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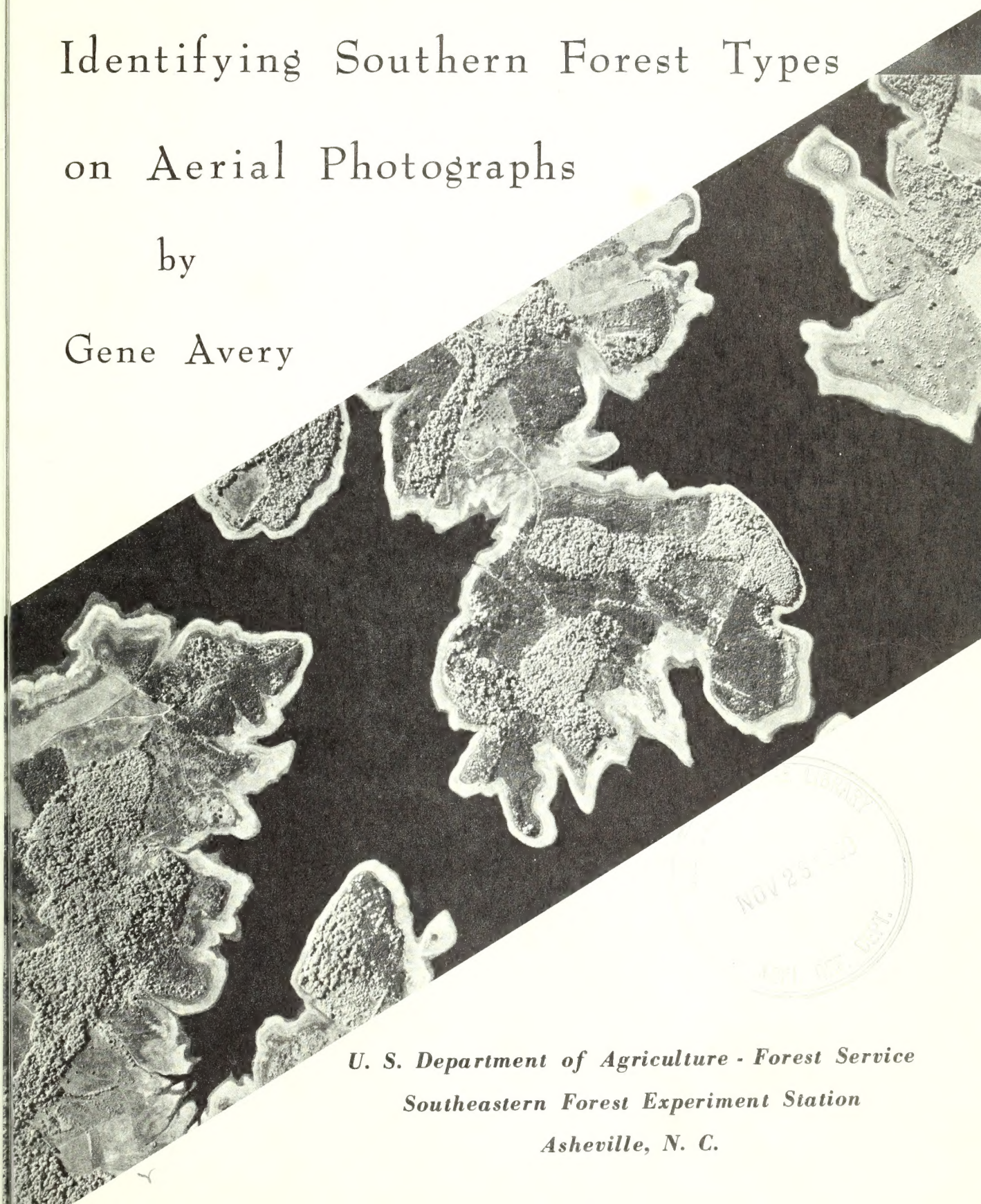
Station Paper No. 112 September 1960

Identifying Southern Forest Types on Aerial Photographs

by

Gene Avery



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Southeastern Forest Experiment Station
Asheville, N. C.

Cover illustration: Portion of an infrared aerial photograph showing mixed pines (dark crowns) and hardwoods (light gray crowns) near Hiawassee, Georgia. Black areas are open waters of the Chatuge Reservoir.

Identifying Southern Forest Types on Aerial Photographs

by

Gene Avery [1]

This booklet has been prepared to assist photo interpreters in recognizing broad forest types on aerial photographs of the South, and to illustrate primary differences between panchromatic and infrared photography from the standpoint of timber type-mapping.

The ability to delineate forest types on vertical aerial photographs is largely a product of field experience and training. For example, a forester who has worked in both northern and southern Georgia can separate most stands of loblolly-shortleaf pines from longleaf-slash pines on the basis of his knowledge of the range and site requirements of the two species-groups. The photographic image enables him to recognize an area as mixed pines, but final determination of the specific type is often accomplished through mental elimination.

The generalized forest type map shown in figure 1 recognizes four basic types: longleaf-slash pines, loblolly-shortleaf pines, upland hardwoods, and bottomland hardwoods. In many instances, of course, finer photo stratifications can be made, depending on the scale and quality of available aerial photography and the ability of individual interpreters.

All photographic illustrations are from 9- by 9-inch aerial prints and are shown at the original scale of 1:15,840 or 4 inches per mile. These panchromatic and infrared photographs are unique in that the paired ex-

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[1] Formerly with the Division of Forest Economics, Southeastern Forest Experiment Station, the author is now Assistant Professor, Department of Forestry, Michigan State University, East Lansing, Michigan.

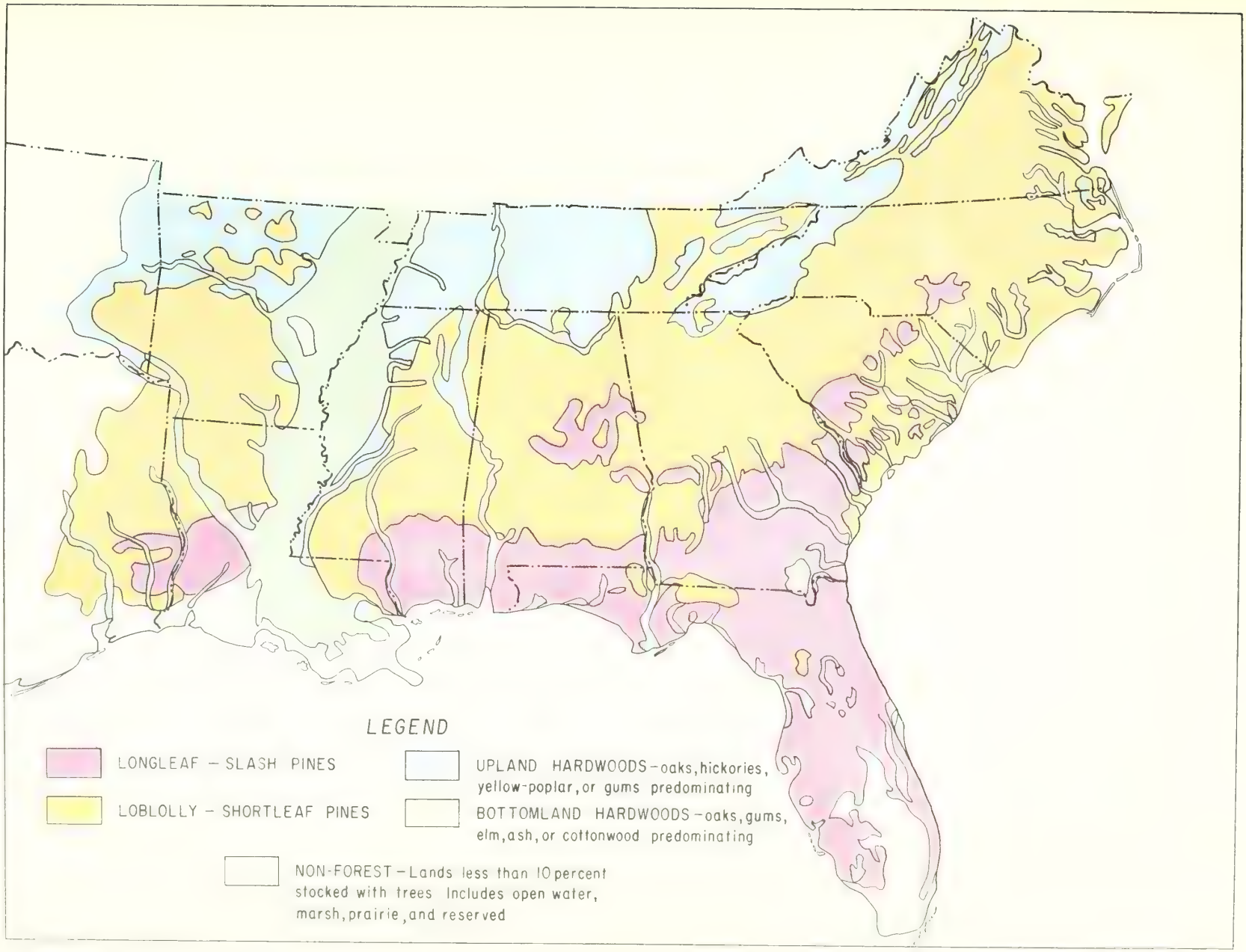
posures were made simultaneously by two aerial cameras mounted in a single aircraft. They were obtained through a cooperative U. S. Navy-Forest Service project, and flights were specifically planned to depict summer forest conditions in the Coastal Plain, Piedmont, and mountains of North Carolina and Georgia. In preparing illustrations for this booklet, an effort was made to select prints that are reasonably typical of these physiographic regions.

Good quality infrared photographs, if taken during spring or early summer, are usually superior to panchromatic prints for delineating southern forest types. This is especially evident from the ensuing illustrations, because of the striking contrast between dark-toned conifers and lighter-toned hardwoods on the infrared photographs. Panchromatic photography offers slightly better image resolution and less offensive shadows, but these items are ordinarily less important to the forester than reliable separation of timber types.

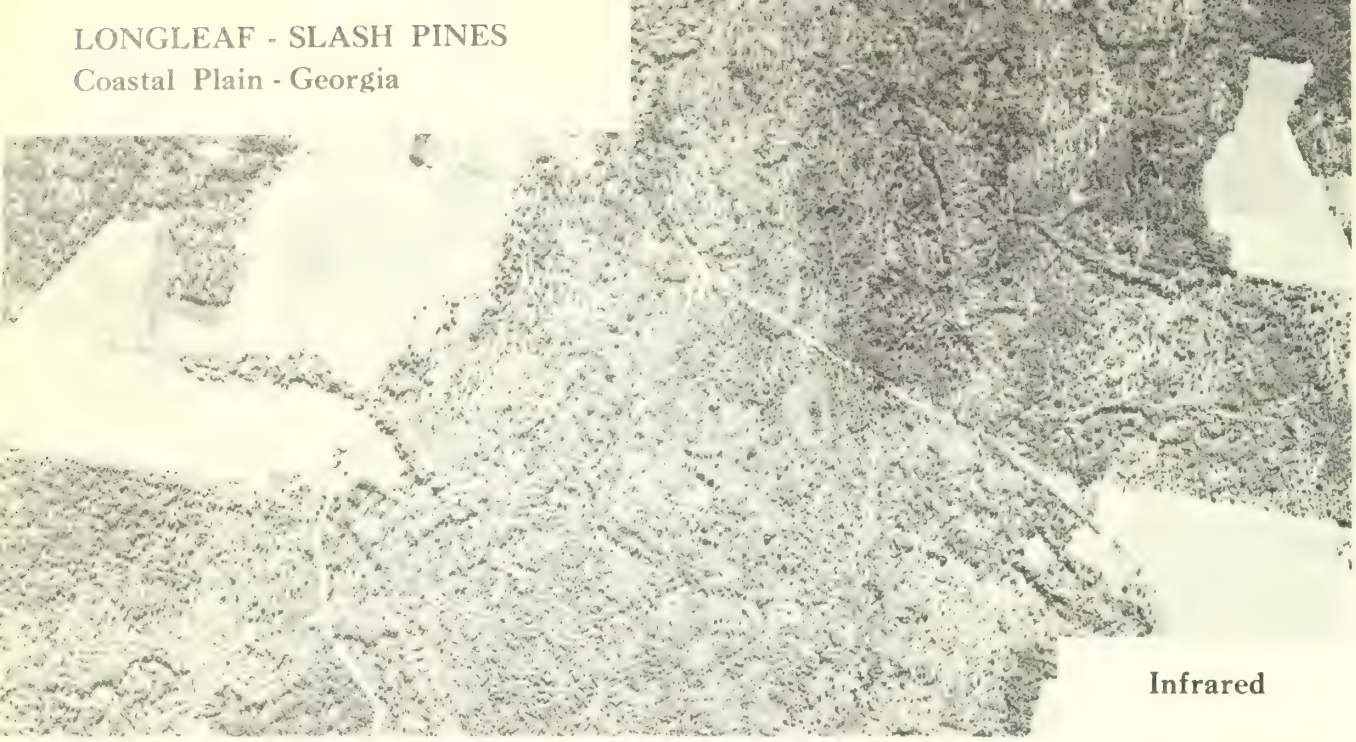
Whenever possible, interpreters should rely on stereoscopic pairs of photographs in delineating forest types, for certain details that are obvious when seen three-dimensionally may pass unnoticed when using single prints. Stereo-pairs are *not* illustrated here, because their advantages are largely forfeited in printing by halftone screening processes. When single prints are used, greatest reliance must be placed on gross identification features, such as distinct tonal contrasts, spatial distribution, physiography, and drainage patterns.

For readers who are occasionally confused by the expression of photo and map scales as representative fractions, a table of conversion factors appears on the final page of this report.

Figure 1.—Generalized forest type map of the South. More detailed information on the range and distribution of softwood species can be obtained from Forest Survey Release 83, issued in 1960 by the Southern and Southeastern Forest Experiment Stations.


LEGEND
LONGLEAF – SLASH PINES
LOBLOLLY – SHORTLEAF PINES
UPLAND HARDWOODS – oaks, hickories, yellow-poplar, or gums predominating
BOTTOMLAND HARDWOODS – oaks, gums, elm, ash, or cottonwood predominating
NON-FOREST – Lands less than 10 percent stocked with trees Includes open water, marsh, prairie, and reserved

LONGLEAF - SLASH PINES
Coastal Plain - Georgia



Infrared

Figure 2.—Longleaf and slash pines, occurring in pure stands or in mixtures with upland oaks, comprise the dominant forest cover on the broad, sandy ridges and flatwoods of the southern Coastal Plain. Natural stands are typically open-grown, often sparsely-stocked, and intercepted by denser zones of bottomland hardwoods that follow irregular drainage courses. This dendritic pattern of hardwood distribution is defined by very light tones on infrared photography (*above*), and the darkest tones on panchromatic prints (*below*).

Longleaf crowns often exhibit a lighter tone than slash pines on infrared photography, but little contrast between these species is evident on panchromatic photos. Where tree shadows fall on level ground, the distinctly pointed and symmetrical character of young longleaf crowns also helps to distinguish this species from slash pine.

Panchromatic

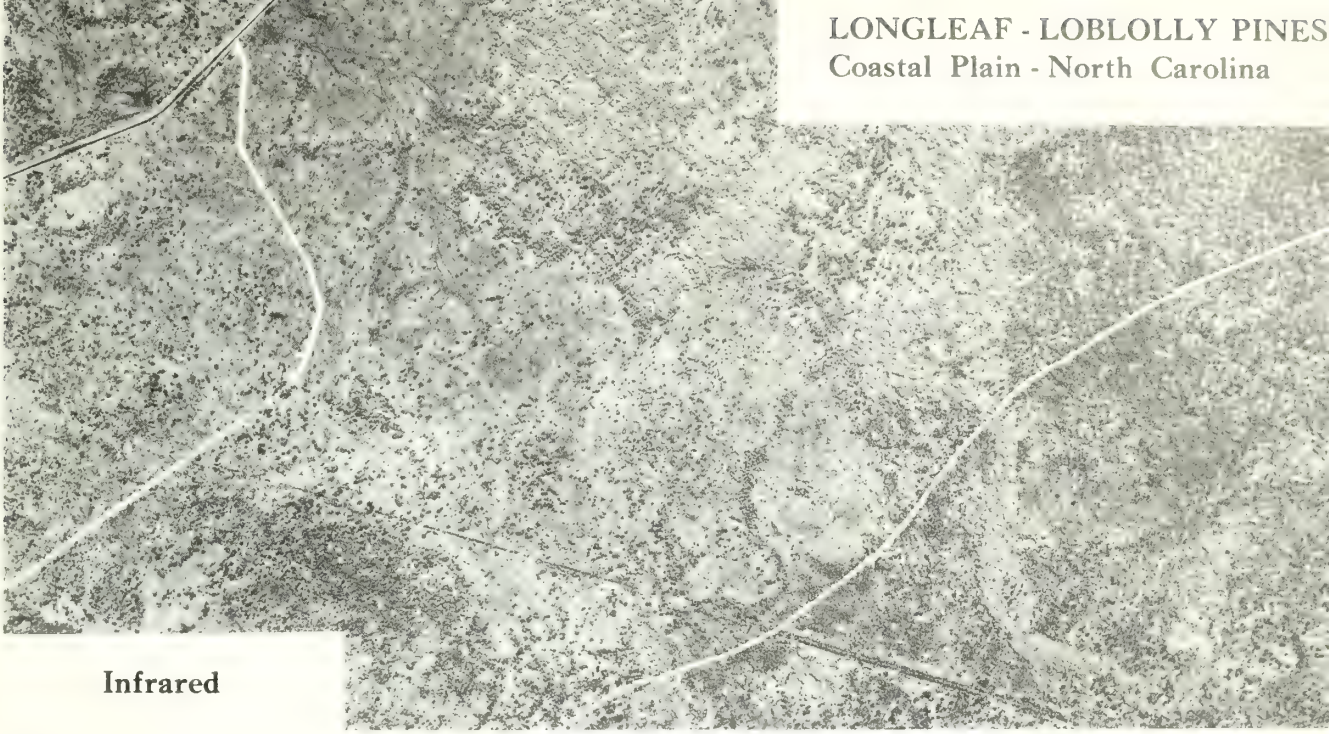
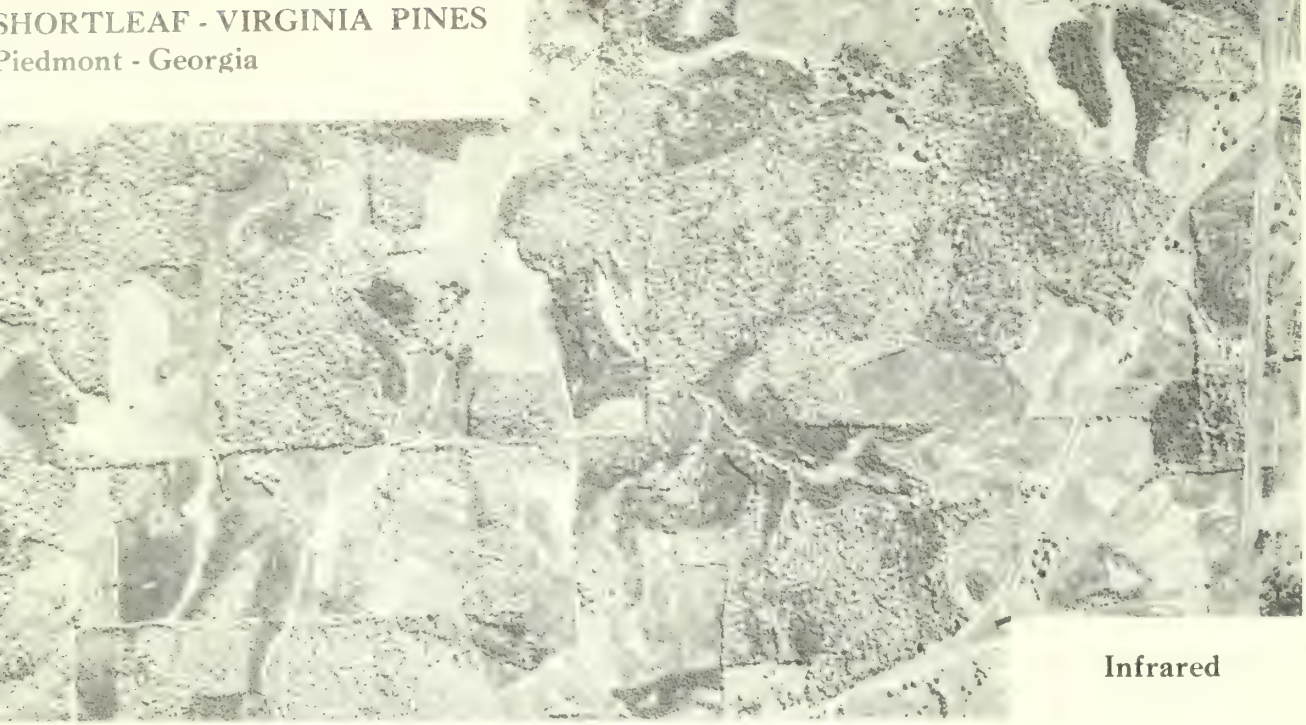


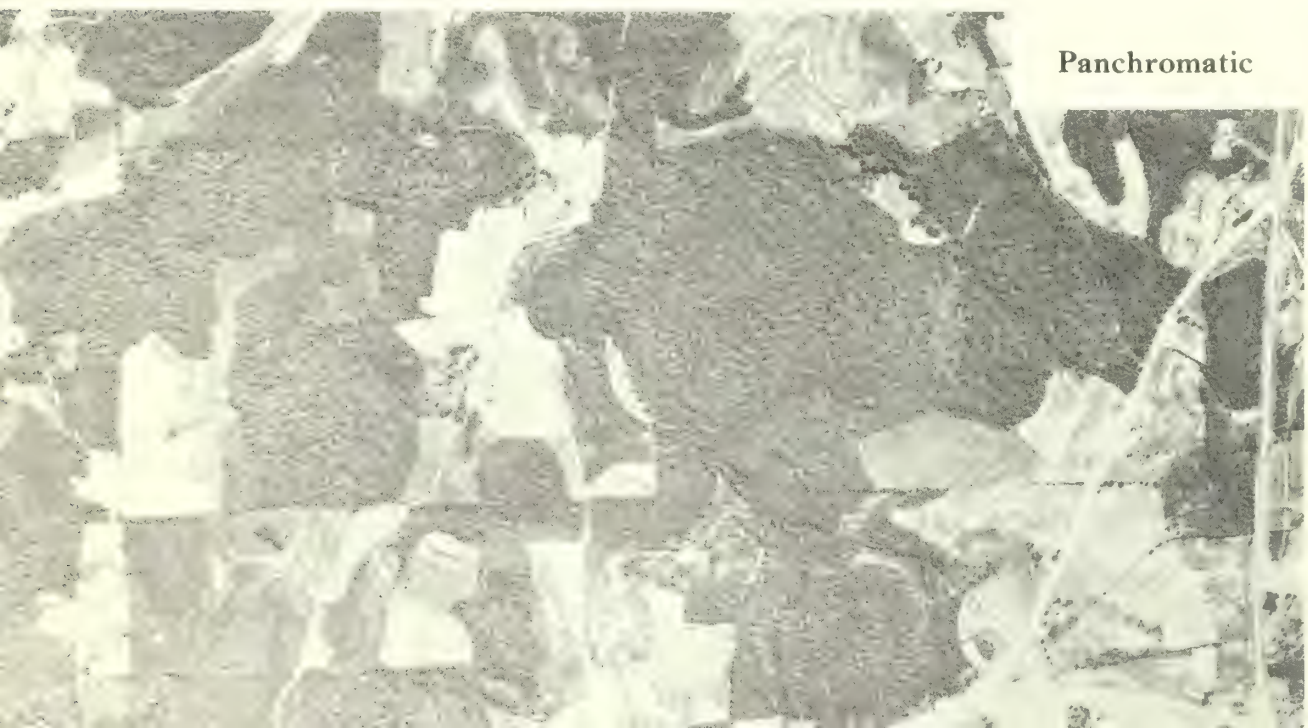
Figure 3.—In the Coastal Plain of North Carolina, longleaf pine may be found in pure stands or in mixture with low-quality hardwoods on dry, upland sites such as the Sandhills area. Loblolly pine commonly occurs on moist sites, occasionally in mixture with bottomland hardwoods, while pond pine is most likely to be encountered in the elliptical-shaped depressions known as *pocosins* or Carolina bays. Slash pine occurs only in plantations, as the natural range of this species does not extend into North Carolina. In the infrared photograph (*above*), the darker crowns are longleaf and loblolly pines in varying mixtures with upland hardwoods.



Infrared

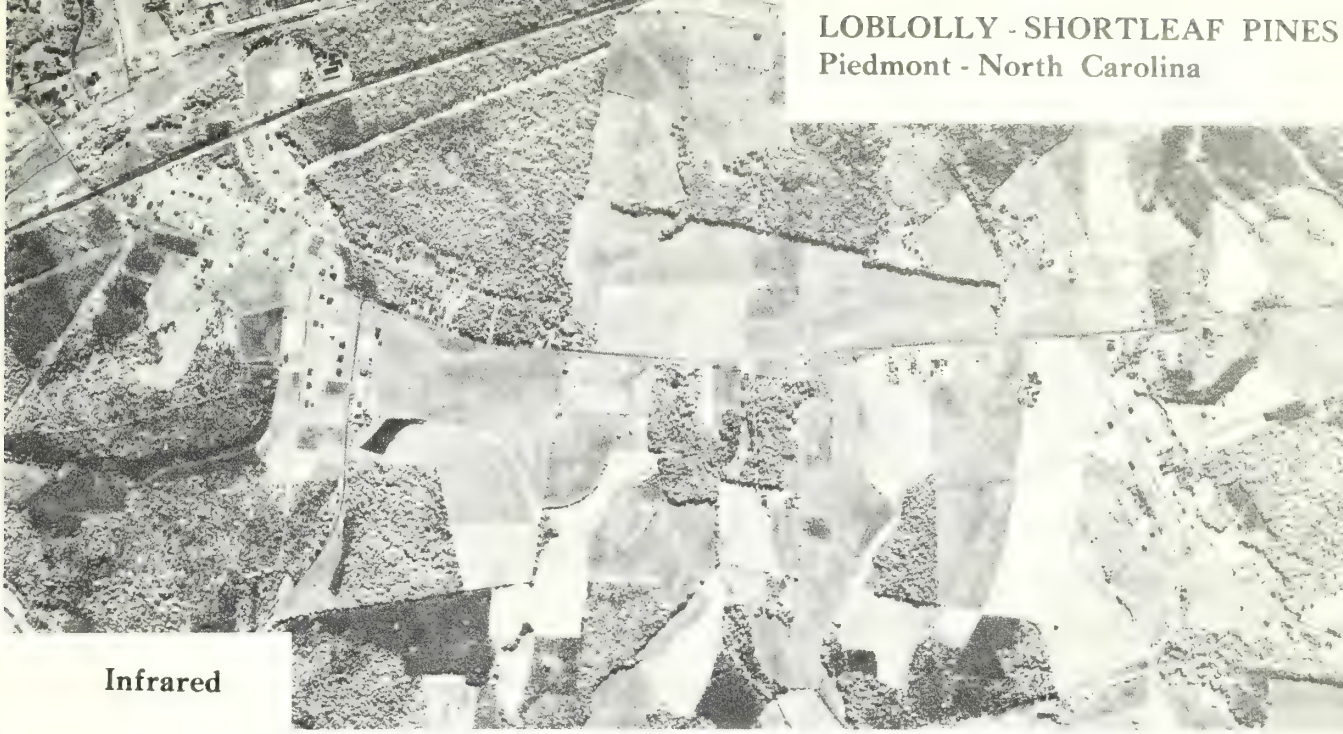
Figure 4.—In the upper Piedmont, shortleaf and Virginia pines are characteristically found growing in close association with upland oaks and hickories. Field contours on these photographs indicate that the topography is relatively steep in this region. Because few natural stands of loblolly pine are found in this sector of northeast Georgia, it may be presumed that most of the conifers shown here (dark crowns on infrared print) are shortleaf and Virginia pines.

These prints constitute a classical comparison of infrared and panchromatic aerial photography for timber type-mapping. Both pure and mixed stands can be readily delineated on the infrared photograph, but type separations would be much more difficult on the even-toned panchromatic print, especially in the case of pine-hardwood mixtures.



Panchromatic

LOBLOLLY - SHORTLEAF PINES
Piedmont - North Carolina



Infrared

Figure 5.—An irregular patchwork of small farms and woodlots typifies the rolling topography of the lower Piedmont. The original forest cover was predominantly oak-hickory and mixed stands of upland hardwoods, loblolly, and shortleaf pines. Added to these during the past 10 to 15 years have been many small plantations of loblolly pine.

On the infrared photograph above, pine plantations and mixed pine-hardwood stands are easily identified. The plantations may also be detected on the panchromatic print by noting the uniform, fine-textured crown patterns, but separation of mixed pine and hardwood stands is more tedious. Light-colored fields indicate recent planting, while the darker ones reflect the beginning of a new crop or pasture lands. A few abandoned areas shown are reseeding naturally to pines.

Panchromatic

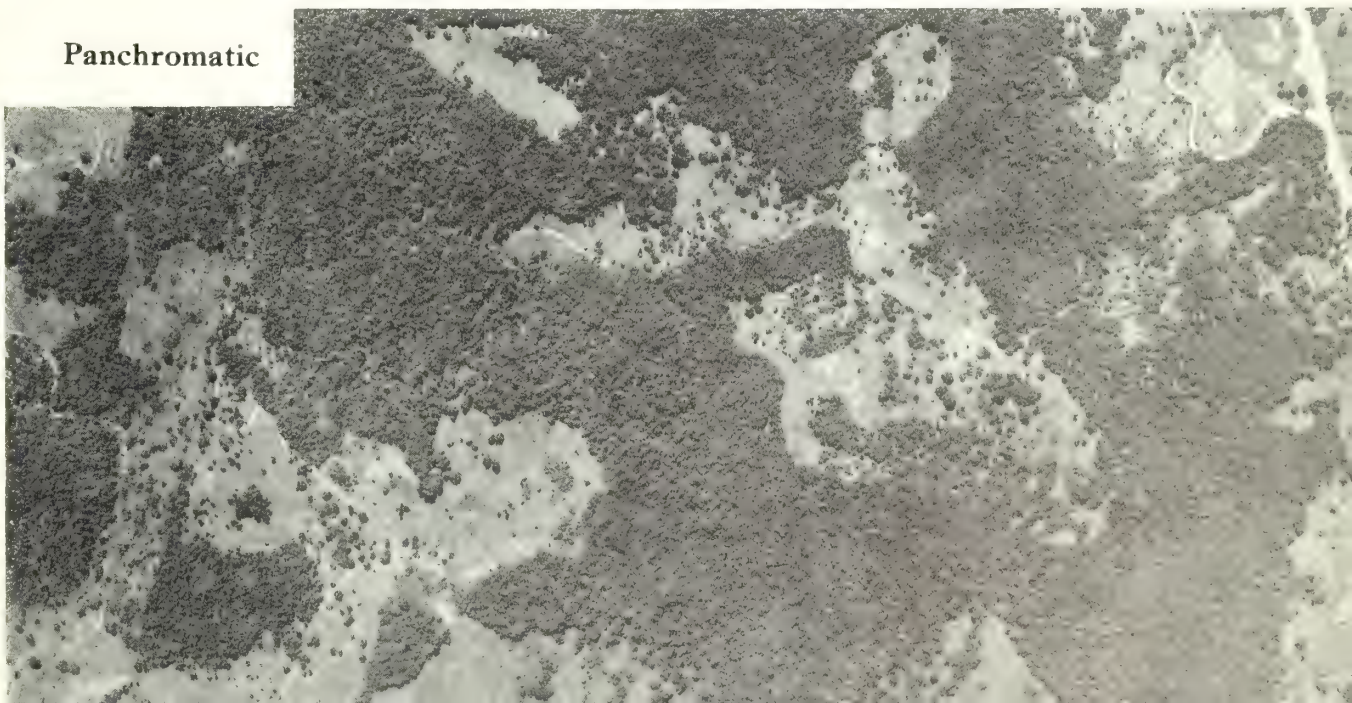
Infrared

Figure 6.—The large, round-topped hardwoods here (light gray on infrared print) are mostly upland oaks with lesser quantities of hickories and yellow-poplar. The dark-toned conifers are presumably shortleaf, Virginia, or pitch pines. Natural stands of loblolly pine are not found in extreme northeast Georgia.

These illustrations also show the edge of a large reservoir; a large dam and spillway are visible at the top center of each photograph. On the panchromatic print, water in the reservoir and drainage channel appears in a normal gray tone, while it shows up typically black on the infrared exposure.

Panchromatic

Figure 7.—These photographs from western North Carolina show stands of essentially pure upland hardwoods on ridge tops and upper slopes, while the valleys and lower slopes are devoted to pasture and cropland. Here again, oaks and hickories predominate, with yellow-poplar occurring frequently in coves and on the better, moist sites. Note that roads, trails, and field boundaries are much more easily traced on the panchromatic photograph than on the infrared print.



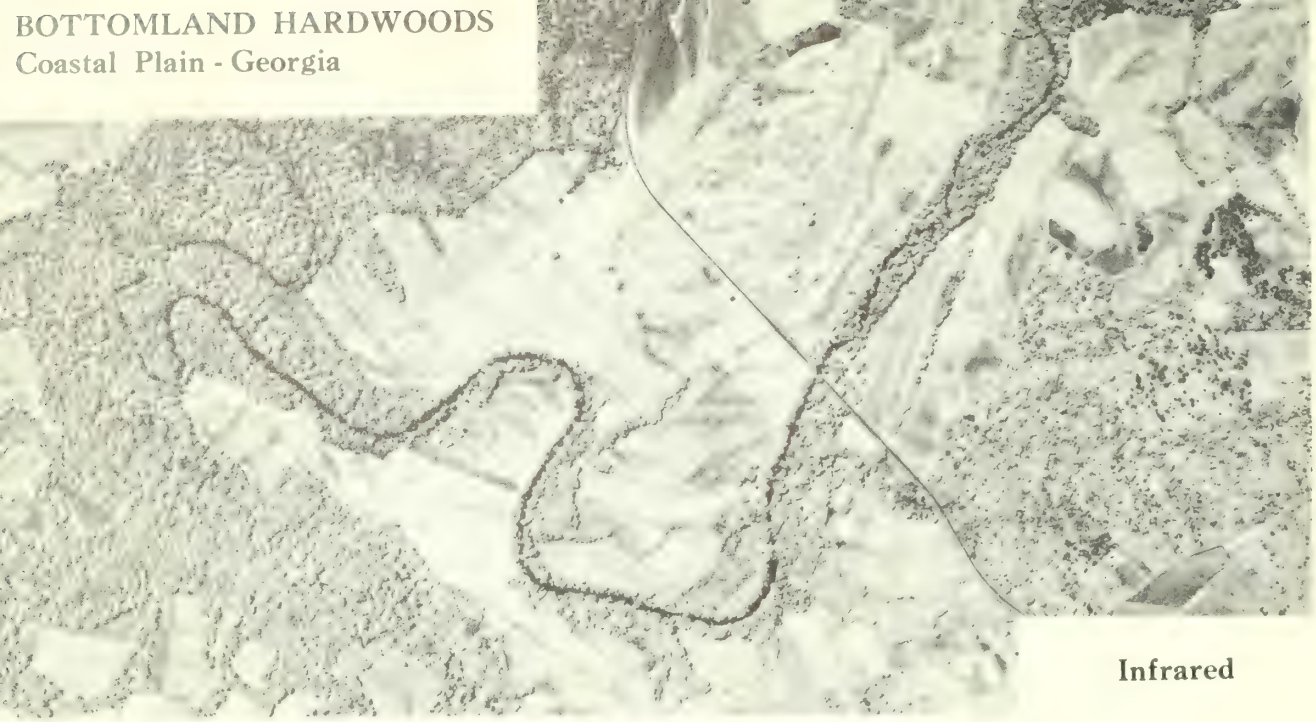


Figure 8.—Species such as cypress, gums, oaks, maples, and magnolias are commonly found in lowland areas and along stream bottoms of the Coastal Plain. Loblolly or spruce pines may also occur in mixture with these hardwoods, as evidenced by the patches of dark crowns at the top of the infrared photograph.

Bottomland hardwood sites are characterized by meandering streams, oxbow lakes, and standing water. Except for cypress-gum stands, heavy shadows and wet soils usually result in photographic tones that are darker than for upland hardwoods, particularly on infrared photographs.

Figure 9. — Individual bottomland hardwood species are rarely separable except where they occasionally occur in pure stands. However, some inferences may be made with regard to type where sharp tonal boundaries exist as on the infrared print above. In areas marked "A," pines are growing in mixture with oaks and gums on relatively well-drained sites; the recently-vegetated flood-plain at "B" is likely to support such wet-site species as gums, cypress, or sycamore; and "C" represents a marshy flat that is currently unsuitable for tree growth.

Cypress can ordinarily be identified only when it occurs in pure stands, as in the small coastal "ponds" that resemble the Carolina bays. When viewed stereoscopically on high-quality photographs, cypress crowns exhibit a light-toned, roughly star-shaped appearance, somewhat like that of tropical palms.

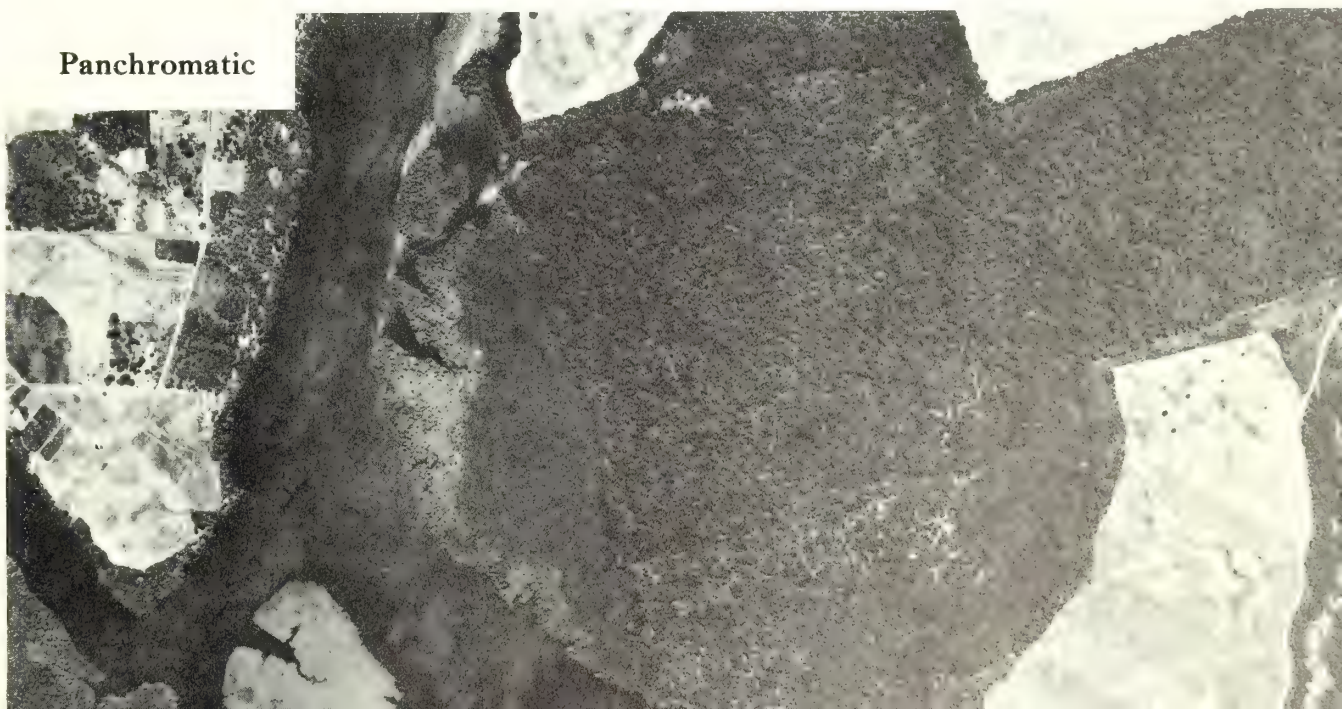


Table 1.—*Scale conversions for vertical aerial photographs* [1]

Representative fraction (scale)	Feet per inch	Chains per inch	Inches per mile	Acres per square inch	Square miles per square inch
(1)	(2)	(3)	(4)	(5)	(6)
1: 7,920	660.00	10.00	8.00	10.00	0.0156
1: 8,000	666.67	10.10	7.92	10.20	0.0159
1: 8,400	700.00	10.61	7.54	11.25	0.0176
1: 9,000	750.00	11.36	7.04	12.91	0.0202
1: 9,600	800.00	12.12	6.60	14.69	0.0230
1:10,000	833.33	12.63	6.34	15.94	0.0249
1:10,800	900.00	13.64	5.87	18.60	0.0291
1:12,000	1,000.00	15.15	5.28	22.96	0.0359
1:13,200	1,100.00	16.67	4.80	27.78	0.0434
1:14,400	1,200.00	18.18	4.40	33.06	0.0517
1:15,000	1,250.00	18.94	4.22	35.87	0.0560
1:15,600	1,300.00	19.70	4.06	38.80	0.0606
1:15,840	1,320.00	20.00	4.00	40.00	0.0625
1:16,000	1,333.33	20.20	3.96	40.81	0.0638
1:16,800	1,400.00	21.21	3.77	45.00	0.0703
1:18,000	1,500.00	22.73	3.52	51.65	0.0807
1:19,200	1,600.00	24.24	3.30	58.77	0.0918
1:20,000	1,666.67	25.25	3.17	63.77	0.0996
1:20,400	1,700.00	25.76	3.11	66.34	0.1037
1:21,120	1,760.00	26.67	3.00	71.11	0.1111
1:21,600	1,800.00	27.27	2.93	74.38	0.1162
1:22,800	1,900.00	28.79	2.78	82.87	0.1295
1:24,000	2,000.00	30.30	2.64	91.83	0.1435
1:25,000	2,083.33	31.57	2.53	99.64	0.1557
1:31,680	2,640.00	40.00	2.00	160.00	0.2500
Method of calculation	$\frac{RFD}{12}$	$\frac{RFD}{792}$	$\frac{63,360}{RFD}$	$\frac{(RFD)^2}{6,272,640}$	$\frac{\text{Acres/sq. in.}}{640}$

[1] Conversions for scales not shown can be made from the relationships listed at the bottom of each column. Using the scale of 1:7,920 as an example (col. 1, line 1), the number of feet per inch is computed by dividing the representative fraction denominator (RFD) by 12 (no. of inches per foot). Thus, 7,920÷12=660 feet per inch (col. 2). By dividing the RFD by 792 (inches per chain), the number of chains per inch is derived (col. 3). Other calculations can be made similarly. Under column 4, the figure 63,360 represents the number of inches in one mile; in column 5, the figure 6,272,640 is the number of square inches in one acre; and in column 6, the number 640 is acres per square mile.

Silvical Characteristics of Shumard Oak

by

Thomas Lotti

Station Paper NO 113

October 1960

U.S. DEPARTMENT OF AGRICULTURE
FOREST SERVICE
Southeastern Forest Experiment Station
Asheville, North Carolina

Silvical Characteristics of Shumard Oak

(Quercus shumardii Buckl.)

by

Thomas Lotti
Charleston Research Center

Shumard oak (Quercus shumardii Buckl.), also known as Schneck oak, Schneck red oak, Shumard red oak, southern red oak, spotted oak, and swamp red oak, is found along the Atlantic Coastal Plain from North Carolina to northern Florida and along the Gulf of Mexico to eastern and central Texas; north in the Mississippi Valley to southwestern Oklahoma, eastern Kansas, southern Illinois, Indiana, and southern Ohio; and in localities in southern Pennsylvania, Maryland, and West Virginia (6) (fig. 1).

HABITAT CONDITIONS

CLIMATIC

Shumard oak grows in a climate which is primarily of a humid, temperate nature, characterized by hot summers and mild, short winters (12). Through the major part of the tree's commercial range, the growing season extends from 210 to 250 days, with average annual temperature from 60° to 70° F., and average annual precipitation from 45 to 55 inches. Within this area the annual maximum temperature is about 100° F. and the annual minimum about 15° F. Half or more of the rainfall occurs during the warm season, April through September. The tree's ability to grow in a severe climate is shown by its presence in parts of Texas and Oklahoma where the average annual rainfall is only 25 inches.

EDAPHIC AND PHYSIOGRAPHIC

Shumard oak attains its best development in the southern forest on moist, well-drained loamy soils found on terraces, colluvial sites, and adjacent bluffs associated with large and small streams. It is also found in coastal plain hammocks, but rarely occurs on first bottom sites (9). In central Texas and Oklahoma, the tree grows on dry, low limestone hills (11). In the southern part of the Central Forest, extending into the Southern Forest and to the borders of the western prairies, it also occurs on dry uplands and ridges (11).

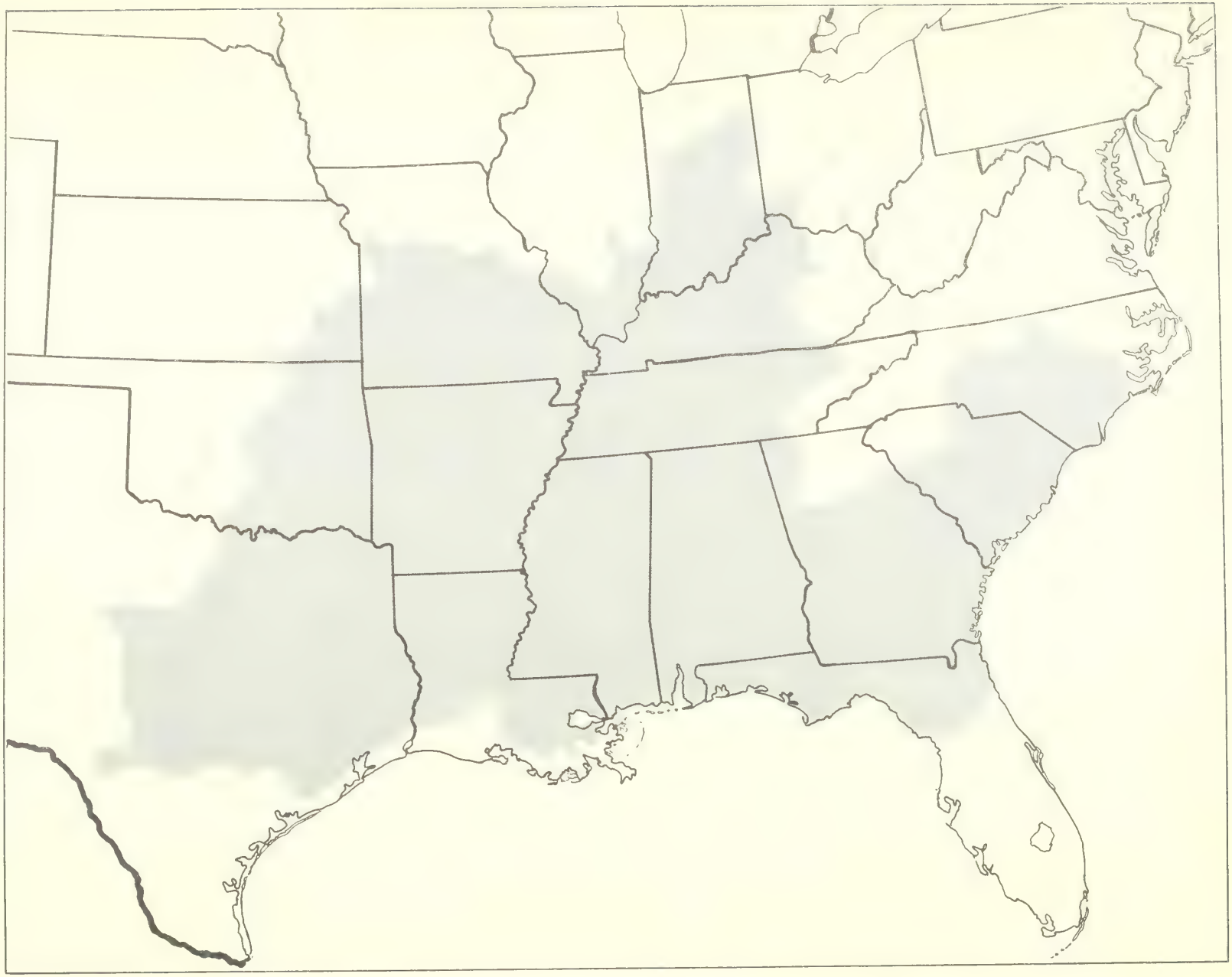


Figure 1.--Botanical range of Shumard oak (Quercus shumardii Buckl.).

BIOTIC

Shumard oak is an associate species in the swamp chestnut oak-cherrybark oak, Ashe juniper ("Mountain Cedar"), and Mohrs ("Shin") oak types of the Southern Forest; and of the post oak-black oak type of the Central and Southern Forests, according to the Society of American Foresters (11).

In the swamp chestnut oak-cherrybark oak type, Shumard oak is classed as a chief associate of the type species, along with white oak (Quercus alba), Delta post oak (Quercus stellata var. mississippiensis), blackgum (Nyssa sylvatica), white ash (Fraxinus americana), shagbark hickory (Carya ovata), shellbark hickory (Carya laciniosa), mockernut hickory (Carya tomentosa), and bitternut hickory (Carya cordiformis) (11). Shumard oak generally occurs as a single tree or in small groups, but it never makes up more than a small part of the stand over a large area (10) (fig. 2).

In the Ashe juniper type, the named conifer (Juniperus ashei) and Shumard oak may be associated with cedar elm (Ulmus crassifolia), hackberry (Celtis occidentalis), Mohrs oak (Quercus mohriana), Durand oak (Quercus durandii) and scrub live oak (Quercus virginiana var. fusiformis). After a harvest cut, the Ashe juniper is often succeeded by Shumard oak (11).

The Mohrs oak type, sometimes referred to as the "oak shinneries," in addition to the type species often includes Shumard oak, scrub live oak, hackberry, American plum (Prunus americana), and holly (Ilex sp.) (11).

Shumard oak is one of the minor associates in the post oak-black oak type; blackjack oak (Quercus marilandica) and miscellaneous hickories are more common associates of the type species Quercus stellata and Quercus velutina (11).

For stream terraces and similar lands having deep, moist, well-drained soils, some of the other common plant associates of the Shumard oak are red buckeye (Aesculus pavia), devils-walkingstick (Aralia spinosa), American hornbeam (Carpinus caroliniana), flowering dogwood (Cornus florida), witch hazel (Hamamelis virginiana), American holly (Ilex opaca), red mulberry (Morus rubra), southern bayberry (Myrica cerifera), and Carolina basswood (Tilia caroliniana) (5).

Shumard oak's place in the ecological succession has not been clearly defined. It is listed among the more prominent southern oaks included in the Oak-Hickory Forest region (2). In general, this forest is characterized by the prevalence of oak-hickory climax communities (2). One of these is the white oak climax forest association found in southeastern Oklahoma on north-facing slopes of the higher mountains and on lower upland slopes near streams; white oak is the dominant species, but one of the characteristic trees is Shumard oak (7). However, it is not definitely established that Shumard oak is a true climax species in most oak-hickory communities where it is found. On the drier habitats west of the Mississippi, where the species is seemingly more aggressive, Shumard oak shows some evidence of being a climax species.

Figure 1.--Botanical range of Shumard oak (Quercus shumardii Buckl.).

Figure 2.--A 50-year-old Shumard oak about to be felled for saw logs. This was a single tree found in a mixed hardwood and loblolly pine stand which averaged about 10,000 board feet per acre, located on a well-drained terrace adjacent to a small stream on the Santee Experimental Forest near Charleston, South Carolina.

LIFE HISTORY

SEEDING HABITS

Flowering and Fruiting

The tree's flowers are unisexual, with the stamens in glabrous 6- to 7-inch-long aments; the pistils are borne singly or paired on pubescent stalks (4). Flowering usually occurs in March or April.

The acorn is borne solitary or in pairs: the nut is oblong-ovoid, and may be up to $1\frac{1}{4}$ inches long and 1 inch in diameter; the cup is saucer-shaped with somewhat pubescent scales (4) (fig. 3). The seed ripens in the second year, usually in September or October, during which time the seed also falls. As in many southern oaks, the nut is subject to attack by acorn weevils, such as Curculio baculi, Curculio rectus, and Curculio pardalis (1). A reliable method of sorting weeviled acorns from sound ones, according to tests at the Santee Experimental Forest, is by color of the cup scar on the nut: a bright, light tan indicates a good acorn, while the bad ones are a dull brown.

Seed Production and Dissemination

Seed bearing begins at about 25 years and reaches optimum production at about 50. Good seed crops occur at intervals of 2 or 3 years, with light crops in between. Sometimes the crop is a total loss. For example, a freeze in April 1955, after flower buds opened, resulted in a complete crop failure in South Carolina in 1956. Dissemination largely depends on the hoarding activity of animals, mainly squirrels. Along terrace margins and in the hilly sections of the tree's range, as in Texas and Oklahoma, gravity dissemination may be important.

Inasmuch as acorns rate at or very near the top of the wildlife food list, there is reason to assume that the Shumard oak supplies its proportionate share of the bird and animal acorn diet. It is reported that acorns constitute over half the animal diet for white tailed deer (Odocoileus virginianus) in Texas (8). At least in the Mohrs oak and Ashe juniper types, Shumard oak acorns are probably an important source of food for the deer herd.

VEGETATIVE REPRODUCTION

Like most southern oaks, it probably sprouts best when young. It is not a prolific sprouter on moist sites, as evidenced by the absence of other than single-stemmed trees in such locations. On dry sites, sprouting is more prolific. As is typical of the oaks, Shumard is considered difficult to propagate by cuttings.

Figure 3. --Typical bark, fruit, twig and bud, and leaves of Shumard oak.

SEEDLING DEVELOPMENT

Establishment

Because Shumard oak is a comparatively intolerant species, reproduction is not easily obtainable except in full light. It is puzzling that this species, which grows to such large size in the coastal plain and Delta regions, should be generally so uncommon and local in its distribution. The acorn is large and highly palatable to animals and this may be one factor restricting its regeneration. Certain site requirements may be important too. For example, in the coastal plain and Delta, Shumard is seldom found except on deep, rich soils supplied with an abundance of moisture but well-drained; this is not entirely typical, as in certain localities, such as in Texas, Oklahoma, northern Mississippi, and western Tennessee, the species inhabits dry, upland sites.

Early Growth

The possibility of regenerating Shumard oak by seeding or planting has not been fully explored. Studies in progress at the Santee Experimental Forest show an average third-year survival of 75 percent for planted 1-0 nursery stock, and 30 percent survival for direct-seeded acorns on sandy loam soils associated with terraces of small streams of the South Carolina Coastal Plain (fig. 4). Total height at the end of 3 years for the acorn sowings was fair, averaging 27 inches, and indicative of the seedling growth of natural regeneration. Average 3-year height growth attained from sowings in full sunlight was 30 inches, compared to 24 inches for those sowed under forest cover and released at end of first growing season.

Figure 4.--Planted Shumard oak (1-0 nursery stock) in middle of fourth growing season. Santee Experimental Forest.

SAPLING STAGE TO MATURITY

Growth and Yield

At its best, Shumard oak is one of the largest southern oaks, developing a straight, tall, clear trunk up to 4 or 5 feet in diameter, with a total height of 90 to 125 feet (4). Diameter growth is good, at least in the coastal plain and Delta regions, averaging 3 to 4 inches in 10 years (9).

Commercially, Shumard oak generally occurs singly or in very small groups. Consequently, areawise volume and yield values for the species are not available. In mixtures with other species, total volumes exceeding 8,000 board feet per acre for all trees are currently classed as heavy sawtimber stands (4). Heavy pole stands will contain over 175 stems per acre of all species 5 to 11 inches d.b.h. (9). In the old-growth forest, mixed stands containing Shumard oak totalled as much as 30,000 board feet per acre.

Reaction to Competition

Light requirements needed to establish natural regeneration induces a heavy growth, at least on moist sites, of annual weeds, vines, briars, and brush. This competition in turn may retard the early development of Shumard oak unless released by cultural treatment.

Principal Enemies

Shumard oak is susceptible to a number of diseases including rots, wilts, and leaf diseases. The most common wood-rotting fungi attacking this oak are species of Fomes, Polyporus, and Stereum. Oak leaf blister (Taphrina caerulescens) may be common in certain years It is understood that oak wilt (Ceratocystis fagacearum) has killed Shumard oak in Missouri.

No insects are known to attack only Shumard oak. However, the species may be subject to attack, especially on poor upland sites, from an almost endless list of insects affecting southern oaks in general. Some of the more common are:

Defoliators.--June beetles (Phyllophaga spp.); orange-striped oakworm (Anisota senatoria); canker worms (Alsophila pometaria and Paleacrita vernata); forest tent caterpillar (Malacosoma disstria); yellow-necked caterpillar (Datana ministra); variable oak leaf caterpillar (Heterocampa manteo); and the red-humped oakworm (Symmerista albicosta) (3).

Borers.--Attacking healthy trees--Red oak borer (Romaleum rufulum) (cambium and outersapwood); carpenter worms (Prionoxystus spp.) (heart and sapwood); and the Columbian timber beetle (Corthylus columbianus) (sapwood) (3).

Borers.--Attacking weakened trees--Two-lined chestnut borer (Agrilus bilineatus) (cambium); tile-horned prionus (Prionus imbricornis) (roots) (3).

Borers.--Attacking dying trees--Oak timberworm (Arrhenodes minuta) (3).

Scales.--Pit-making oak scale (Asterolecanium variolosum) (kills reproduction and tops on older trees) (3).

Galls.--Gouty oak gall (Callirhytis punctata); horned oak gall (Callirhytis cornigera and Andricus clavigerus) (3).

Leaf miners.--Basswood leaf miner (Baliosus ruber) (3).

SPECIAL FEATURES

The wood of Shumard oak is similar to northern red oak (Quercus rubra) and possibly of higher quality (10). It has a mild texture and the quality is generally good, causing the tree to be closely utilized when harvested commercially (10). Its products include high-value face veneer, factory lumber, and the general run of items for which red oak is used.

RACES AND HYBRIDS

No races of Shumard oak are known, but the check list recognizes one variety, Texas oak (Quercus shumardii var. texana) (6). This tree is found mainly in southern Oklahoma (Arbuckle Mountains) and central Texas, including Edwards Plateau. The variety probably is the Shumard oak included in the previously described Mohrs oak cover type.

The reported natural hybrids are (6):

Quercus ×egglestonii Trel. (Quercus imbricaria × shumardii)

Quercus ×hastingsii Sarg. (Quercus marilandica × shumardii)

Quercus ×joorii Trel. (Quercus falcata × shumardii)

Quercus ×moultonensis Ashe (Quercus phellos × shumardii)

Quercus ×mutabilis Palmer and Steyerm. (Quercus palustris × shumardii)

Quercus ×neopalmeri Sudw. (Quercus nigra × shumardii)

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Agriculture - Asheville

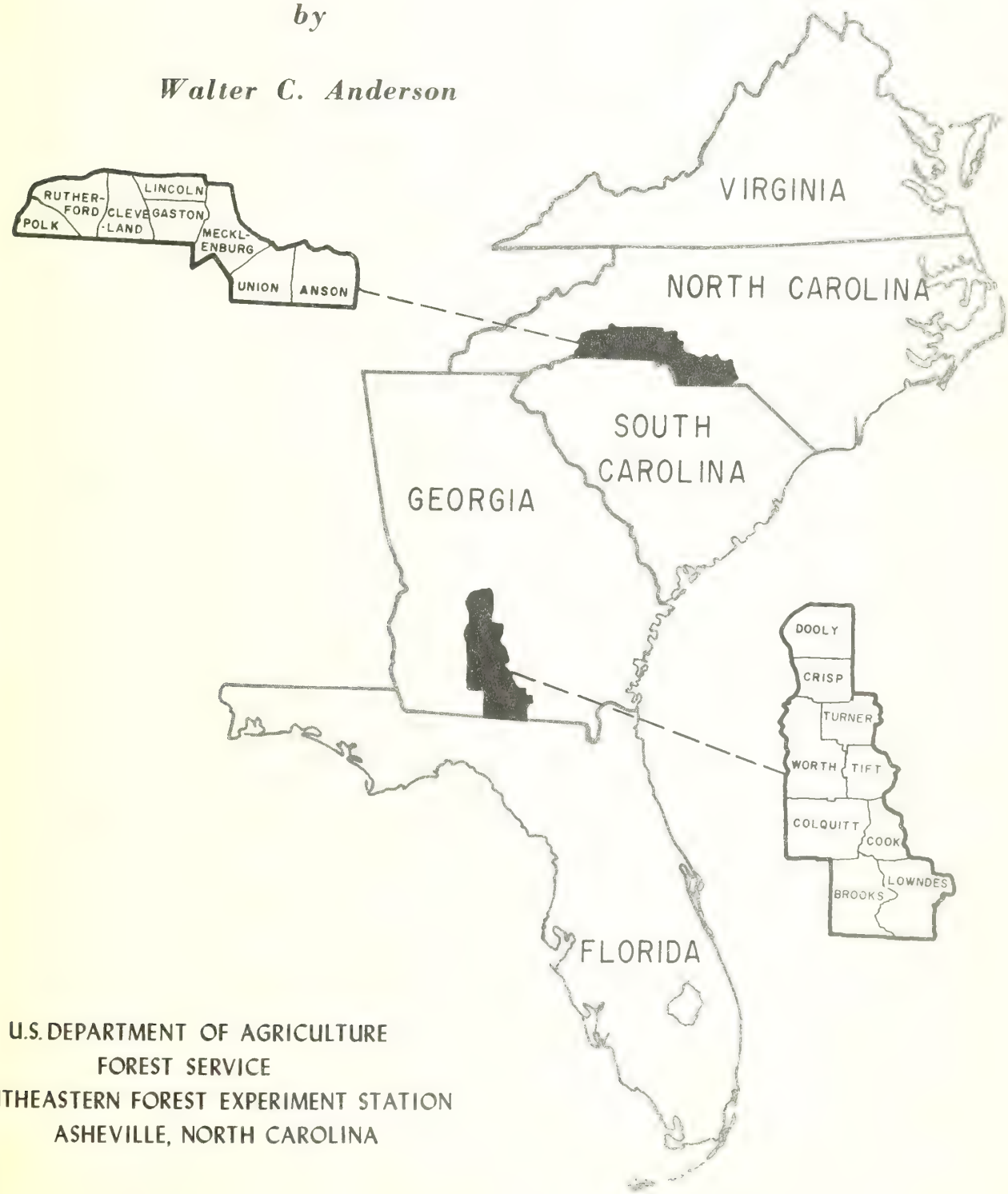
Station Paper NO. 114

October 1960

The Small Forest Landowner and His Woodland

by

Walter C. Anderson



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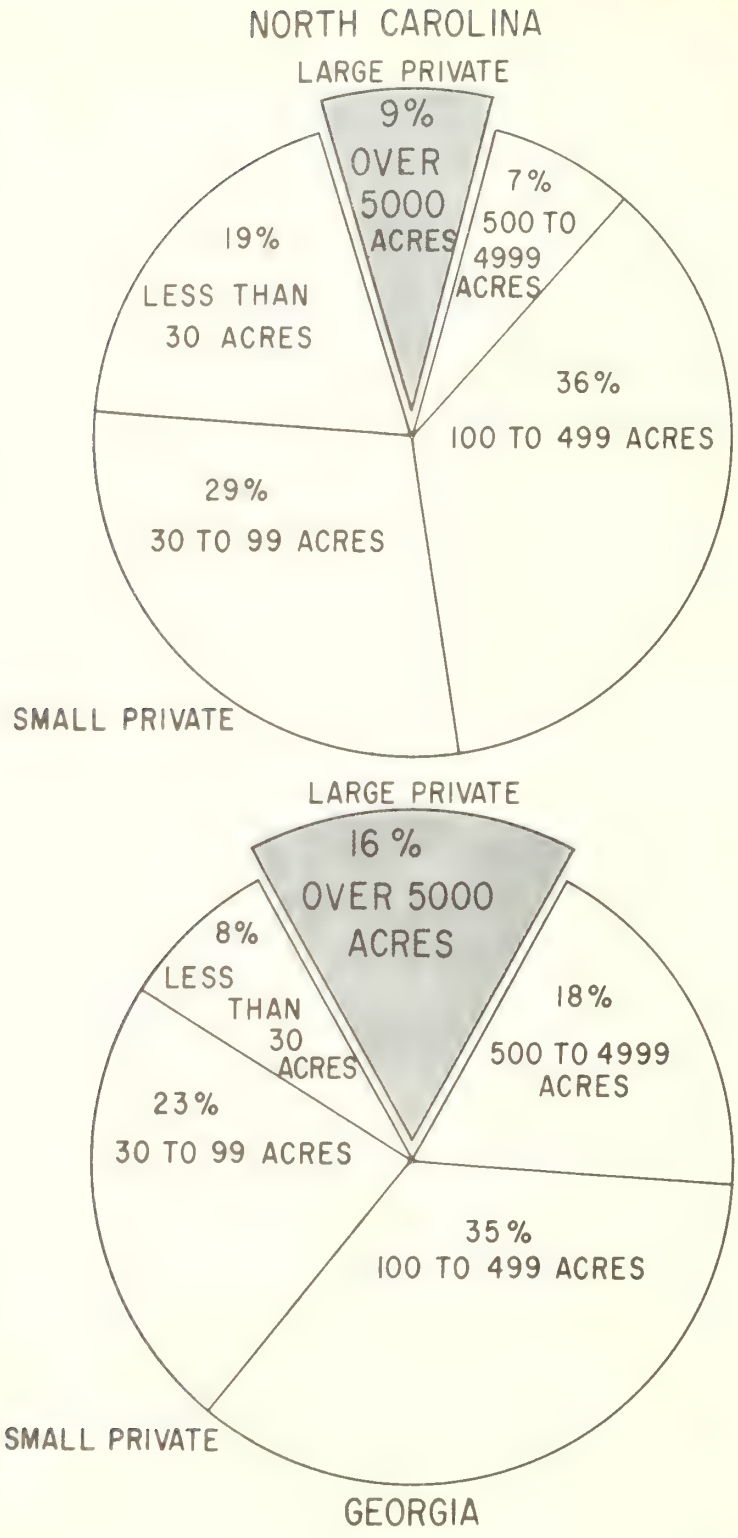


Over two-thirds of the commercial forest land is in private ownerships smaller than 500 acres. The largest area (one-third) is in properties between 100 and 500 acres, well above the marginal size for profitable management. Only a negligible portion is publicly owned.

The Small Forest Landowner and His Woodland

by

Walter C. Anderson

How can wood output from small forest ownerships be increased? This is the number-one problem facing American forestry today.

The problem is especially critical in the Southeast, where small owners hold more than three-quarters of the forest land and this land is in the poorest condition of any class of forest in the United States. Small ownerships are defined as forest properties under 5,000 acres.

Policymakers, industrial leaders, and alert citizens are asking, "Why is there such a difference between the productivity of these properties and that of medium and large holdings?" Although many factors would be involved in a full explanation, owner attitude is among the most important.

To find out what kinds of individuals are particularly interested in forestry and how they use their forest land, 100 owners were interviewed (fig. 1) and their woodlands examined in each of two study areas, one in the North Carolina Piedmont and the other in the Georgia Coastal Plain. Total acreage of the two areas is about the same. And although total acreage in forest is about the same too, forests are of greater economic importance in Georgia than in North Carolina.

Figure 1.--In each study area, 100 small forest landowners were interviewed to find out who these people are and what they are doing with their woodlands.

In the Georgia study area, the population is predominantly rural and farming is the major source of income. The farms are large and the farm families relatively prosperous, so there is scant need for off-farm work. There is, in fact, little industrial employment. The manufacturing plants are small (three-fourths have fewer than 20 employees) and they either make supplies farmers buy or process products farmers sell. Among the most common kinds of firms are lumber and other wood products plants, food processing plants, feed mills, fertilizer plants, cottonseed oil mills, and naval stores distilleries. The forest industries in this area of Georgia provide a large and diversified forest products market.

By comparison, the North Carolina segment is an urbanized and industrialized area. There are several times as many people per square mile, and most of them live in town or in nonfarm homes in the country. In this area with its large textile mills and other industries, much of the labor force works at jobs in manufacturing or trade. This includes many farm operators who supplement their agricultural incomes by working off their farms for a substantial part of each year.

These two areas represent extreme conditions with regard to forestry in the Southeast. In one, people depend on the land, including forests, for their income; in the other, their livelihood is divorced from the land. These segments were purposely picked for contrast. Whenever a situation is found that is common to both, the probability is high that it exists throughout the region.

WHO ARE THE LANDOWNERS?

They are farmers.--Half of the 24,000 North Carolina owners and two-thirds of the 11,000 Georgia owners farm either full time or part time. It is common for a man to have a job in town and still farm the homeplace. The remaining owners are professional persons and businessmen, wage earners and clerks, housewives, and retired people, with wage earners and clerks the most numerous of those in nonfarm occupations (fig. 2).

They are middle aged.--The average age of those in North Carolina is 53 years; the average age of those in Georgia is 57 years. Because of their age, half of all owners can expect to control their land for no more than another 15 years.

They have had their woodlands 18 years.--Typically, they became owners when they were in their late thirties, regardless of how they acquired their land.

They purchased their woodlands.--Few of them were primarily interested in forestry at the time they bought their holdings. Instead, they wanted a property for farming, residence, or some other nonforestry purpose, and the woodland was merely a part of the property they selected.

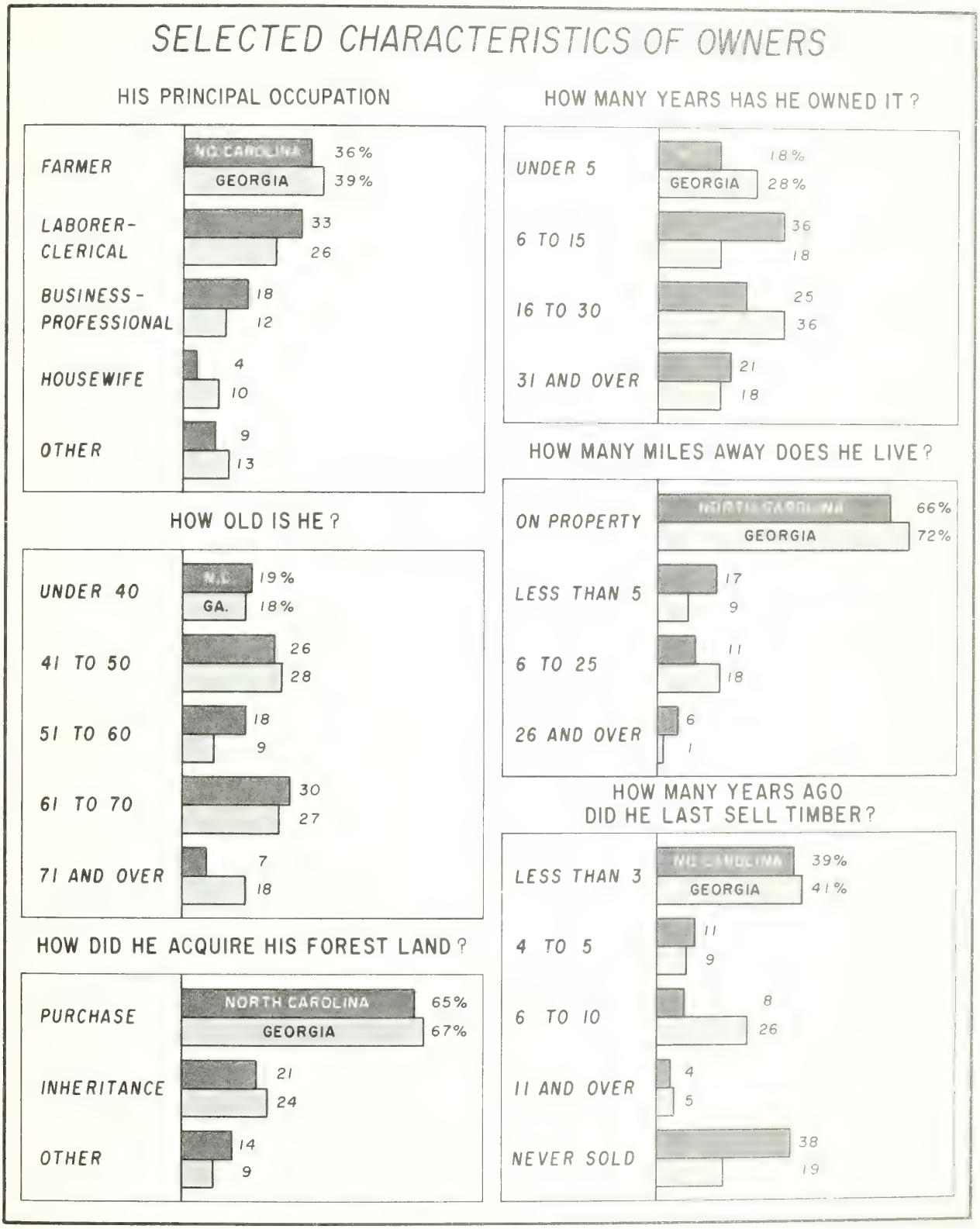


Figure 2.--There is little difference between the two areas in the characteristics of owners, except that many more of the Georgians have sold timber.

They live near their woodlands.--Few live so far away that they could not manage their woodlands if they wished. No serious absentee ownership problem exists, but some owners are functional absentees. One example is a man who lives on the property but obviously never visits his woodland. He thinks it is predominantly a low-grade oak forest, when actually it is made up of thrifty pine and yellow-poplar stands.

They have sold timber, but in an unbusinesslike way.--The few persons who have not sold generally lack timber to sell or will not sell for such reasons as: "My father never sold, and I don't intend to either;" "I want to leave something of value for my kids;" "I don't trust timber buyers." Most individuals who sold timber have sold it within the past few years. Although almost all sales were of stumpage, nine-tenths of the sellers either did not know how much they were selling or relied on the buyer's scale after the timber had already been cut.

WHAT ARE THEIR WOODLANDS LIKE?

They are on farms.--This is to be expected, since few woodlands were acquired specifically for their forest values. Not all of these farms (fig. 3) are farmer-owned, however. Many are owned by people in other occupations.

Woodland covers 40 percent of the property.--The proportion of woodland is generally less on farm than nonfarm properties. Among farms, the largest-size holdings have the greatest proportion of land in forest (fig. 4).

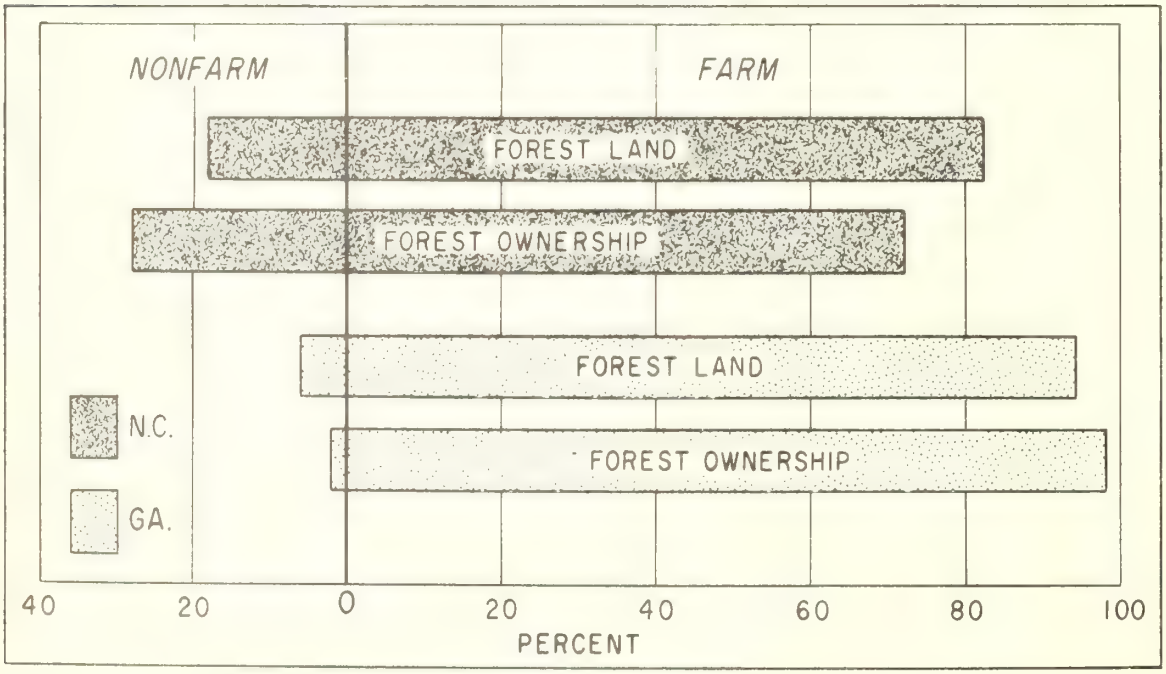


Figure 3.--The fact that most of the forest land and forest ownerships are on farm properties indicates that the small ownership problem is mainly a farm forest problem.

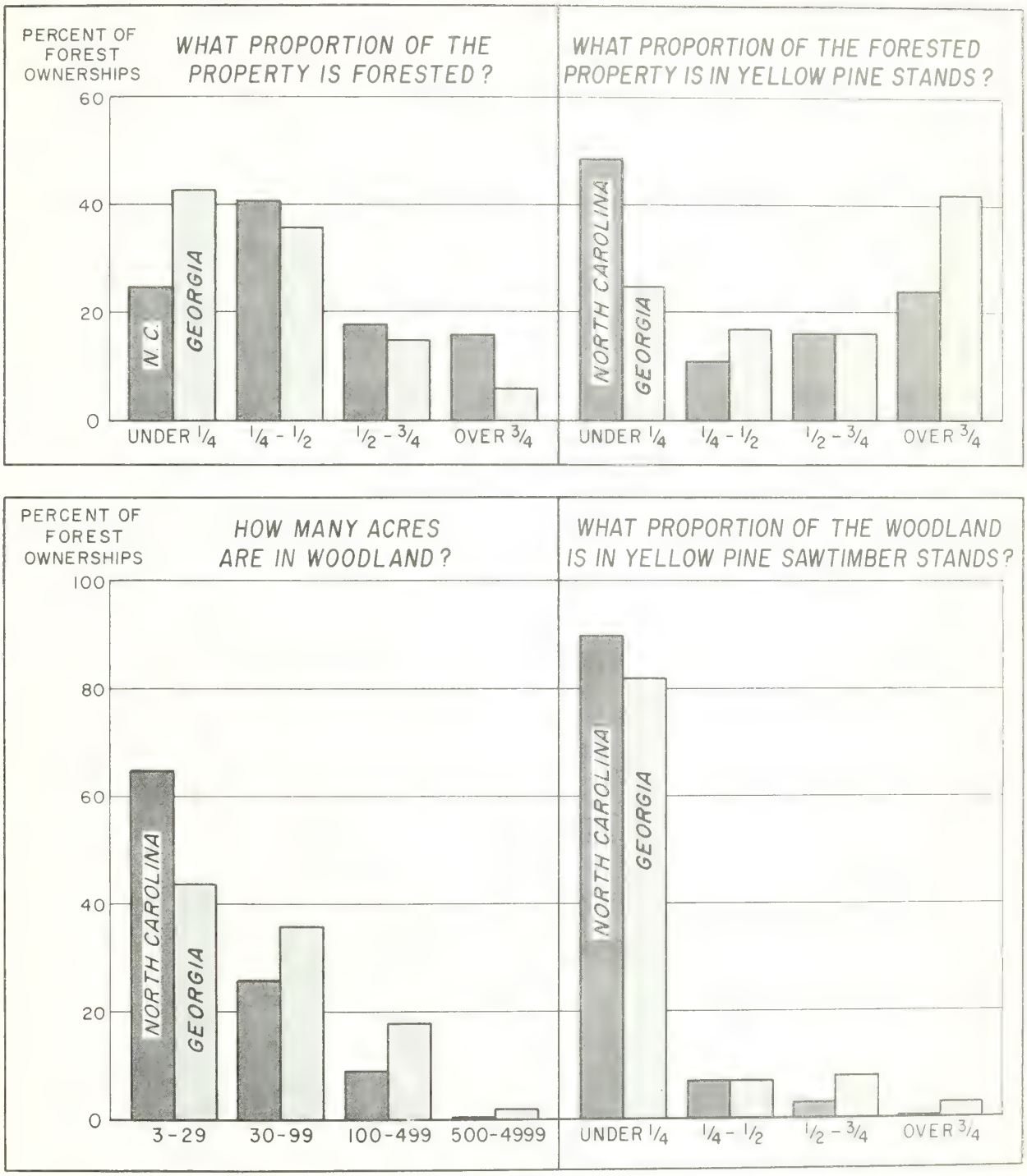


Figure 4. --Well over three-quarters of the woodlands are under 100 acres, and two-thirds of them cover less than half of the property. Where yellow pine stands are present they frequently occupy a large part of the woodland, but only rarely are they of sawtimber size.

Woodlands average 45 acres in North Carolina and 90 acres in Georgia.--Farm woodlands tend to be larger than nonfarm woodlands in North Carolina, while the reverse is true in Georgia. In both areas, the larger the woodland the less likely it is to be in one tract.

Half their area is in yellow pine type.--Yellow pine, of course, is the species of greatest value. But only 15 to 20 percent of the pine area is in sawtimber stands. The remainder is either in poletimber stands suitable only for pulpwood or in seedling and sapling stands not yet merchantable.

Most forest tracts appear worthy of investment.--True, a few are obviously too small for profitable operation, and a few more are clearly in such poor condition as to require costly stand conversion. Nevertheless, the majority of woodlands are large enough to justify management and consist of young stands of valuable species.

HOW DO THEY USE THEIR WOODLANDS?

They use them in a variety of ways.--Among those frequently mentioned are: timber growing, grazing, residence, recreation, mineral extraction, timber liquidation, and clearing for agriculture. Real estate speculation is an additional reason for holding woodland in North Carolina, and the production of gum for naval stores is a woodland use in Georgia. Most owners have some definite use for their woodland.

They are growing timber.--More individuals (40 percent) are devoting their woodlands primarily to this than to any other single purpose (fig. 5). Since, in general, these are the larger landowners, half of all small woodland acreage is dedicated to timber growing.

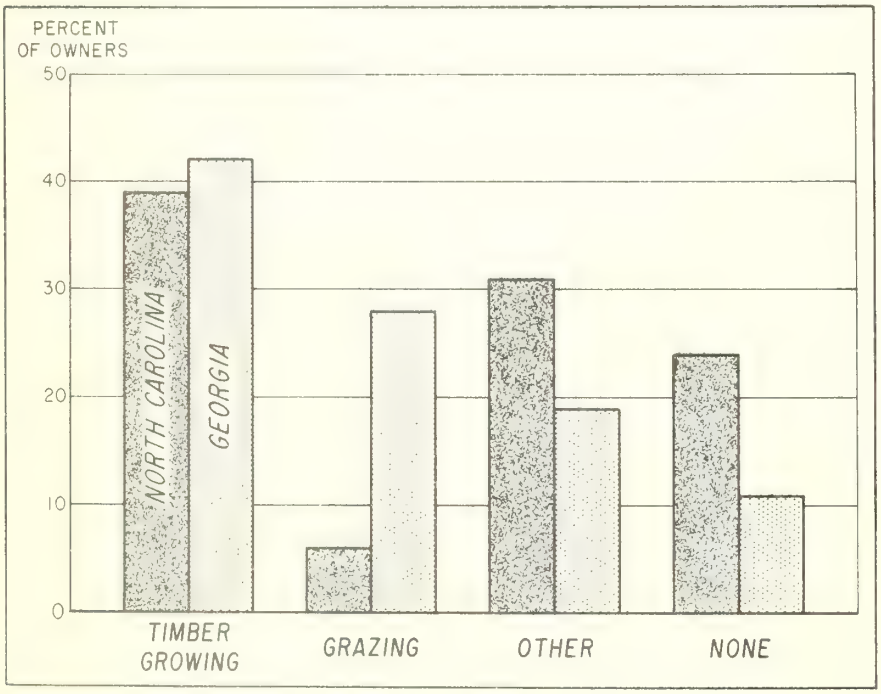


Figure 5.--More woodlands are used principally for timber growing than for any other purpose, although grazing is the main use of many Georgia woodlands.

They also graze their woodlands. --This includes many who are growing timber. Of course, some of these people restrict their cattle to a small part of their woodland or keep so few head that grazing is not heavy. This is truer of North Carolina than Georgia owners. The Georgians tend to accept the theory that woodland grazing benefits the timber by reducing the fire hazard. "Put cattle in your woods, but keep hogs out," advises one of them. His suggestion may be sound when applied to controlled light grazing in open pine stands on sandy coastal plain soils, but almost any prolonged grazing would be detrimental to timber production in the Piedmont, where soils are much more easily compacted.

DO THEY THINK FORESTRY WOULD BE PROFITABLE?

Half think it would. --Those who think so usually have timber cultural measures in mind, such as planting and timber stand improvement (fig. 6). Almost all North Carolina owners who consider forestry profitable mention only practices of this type. On the other hand, Georgians who think that forestry pays quite often include protection measures among the practices they believe are profitable. This difference of opinion may be accounted for by differences between the two study areas. The fact that woodland grazing is more widespread in the coastal plain makes owners in Georgia more aware of the need for fences. And because the incidence of fire is higher in the coastal plain, firelines around individual properties are also considered worthwhile in Georgia.

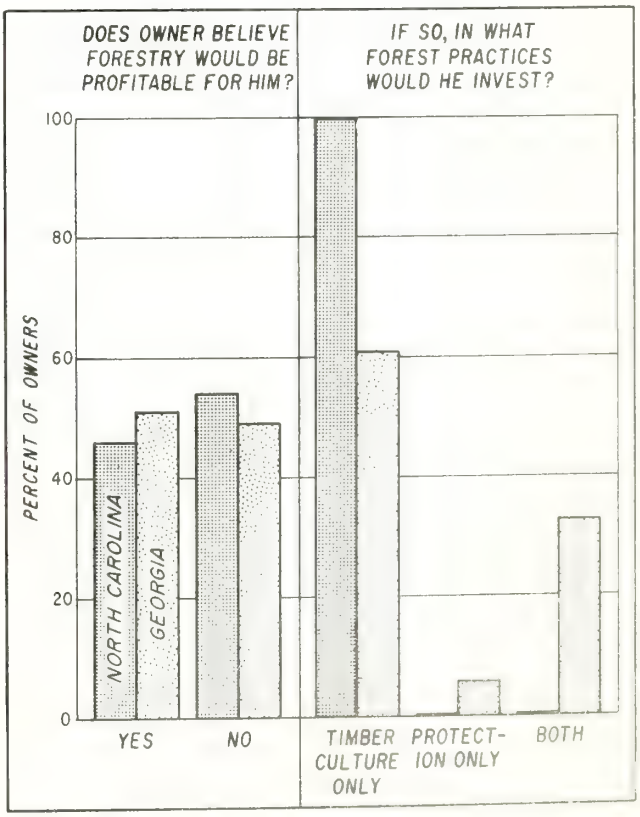


Figure 6. --Half of the owners think that forestry would be profitable. Of these, nearly all feel that timber cultural measures, such as planting or timber stand improvement, will pay. But only a few, mostly in Georgia, recognize that fences, firelines, and other protection measures are worthwhile.

The other half think it would not. --Some of the reasons they frequently give in support of their opinion are: "My woodland is much too small," "Nobody would ever buy the kind of timber I've got," "I'm too old to spend time or money in my woods because I won't live long enough to get any benefit from it," "I can't afford to wait for years until the trees are big enough to sell," "I just don't have the spare money to spend on forestry."

DO THEY PRACTICE FORESTRY?

More than a quarter do. --These might be called active timber growers (fig. 7) to distinguish them from those who merely let nature take its course. Because each owner was allowed to decide for himself whether or not he was a timber grower, some put themselves in this class merely because they refrain from cutting. As one of these owners explains, "I won't cut any more because I'm holding this timber for my two boys." Of course, nearly all owners who have practiced forestry consider themselves timber growers.

They have carried out only one practice. --Since forest management generally requires a series of successive, related practices, hardly any of these active timber growers can be said to be managing their woodlands. Only a few have carried out as many as two practices. And it is a rare individual who has undertaken three or more.

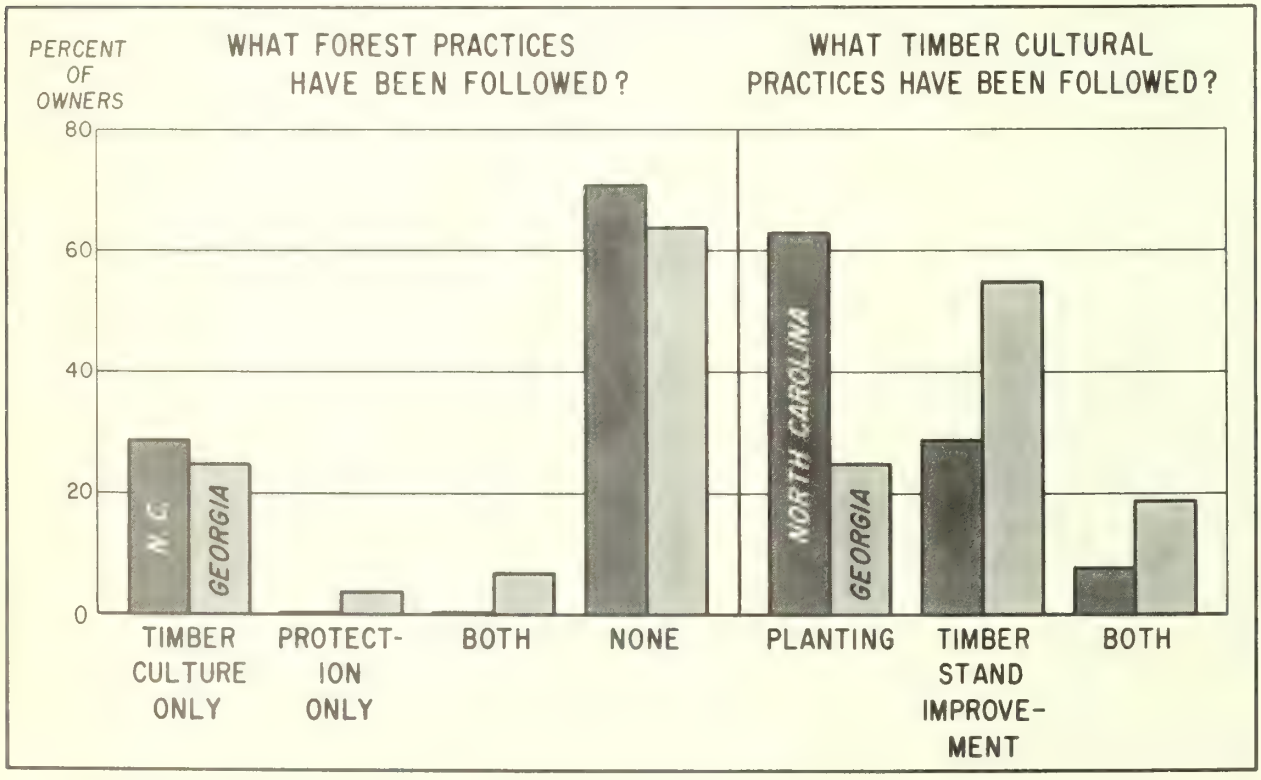


Figure 7. --Of the modest proportion of owners who practiced forestry, the majority in North Carolina planted and most in Georgia did timber stand improvement work.

They have done timber stand improvement work. --This is the practice most frequently reported in Georgia, where many owners did the work themselves. It quite often consisted of cutting worked-out turpentine trees, a job which can be done without professional guidance (fig. 8).

Actually, almost every woodland in both study areas that has been marked by a forester has been marked for timber stand improvement. Foresters apparently are used more often for timber marking than for any other specific purpose.

Although both public and private foresters are available to mark stands and give other technical assistance, many owners have not taken advantage of this service. Some state frankly that they do not know in what way a forester could help them. Others want forestry advice, but either do not know foresters' services are available or have been unable to locate them.

Figure 8. --Of the Georgia owners who practice forestry, most of them do timber stand improvement work such as removing worked-out turpentine trees.

They have planted trees.--This is the most popular practice in North Carolina (fig. 9) and the second most popular in Georgia.

Of course, tree planting is encouraged by public programs such as the one through which the State Forester distributes seedlings. He provides at least moderate quantities of seedlings, either free or at cost. The effectiveness of this program is indicated by the fact that most persons who purchase planting stock from private nurseries started planting with stock received through this public program. In addition, some forest industries also provide seedlings.

Another form of aid to stimulate tree planting is the system of incentive payments made through the Agricultural Conservation Program. ACP forestry payments are designed to encourage owners to carry out practices they might not otherwise perform, by having the Government absorb part of the cost. Even though there are several forest practices that qualify, nearly all ACP payments are for tree planting. Nevertheless, about four-fifths of the owners who planted are unfamiliar with this program and have not received any payments.

In both sample areas, the planting that has been done is on a minor scale (fig. 10). Georgia plantations average 26 acres, and North Carolina plantations only four acres. Seven percent of the forest acreage in Georgia is in plantations, and only two percent in North Carolina.

Figure 9.--In North Carolina, planting is the most popular forest practice, albeit the plantations are small.

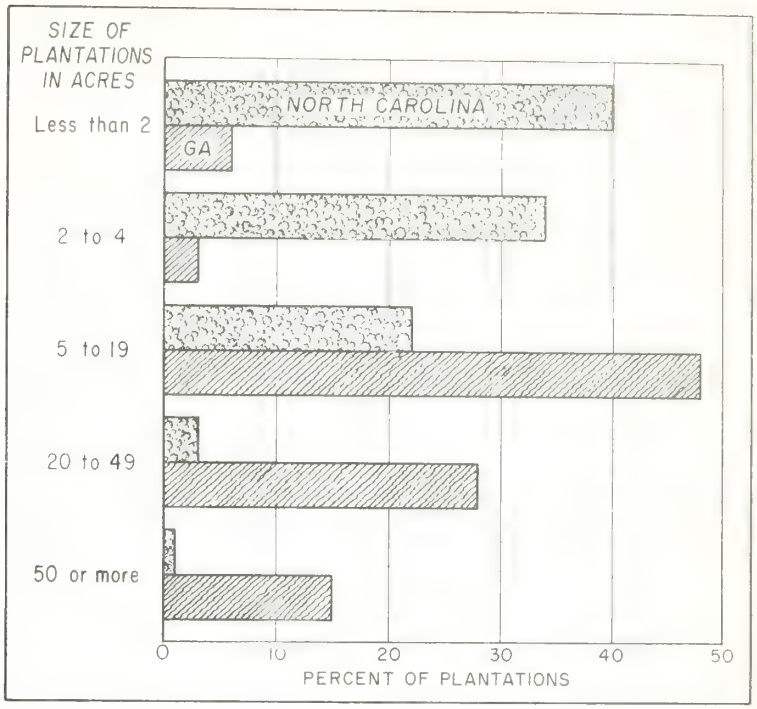


Figure 10. --Typically, forest plantations are small. This is especially true in North Carolina, where owners have only restricted areas that can be planted on their lesser-size properties.

Of course, there are many owners who have not planted at all. The most frequent explanation they give is, "I don't have any land that needs planting." Others say they are simply too busy with farm or other work to have time to plant. Still, some of these individuals would plant if they could find the labor to do it. Most, however, could not afford to employ the labor even if it could be hired. A number of the poorer owners say they would have planted had they known public assistance was available. But a few others, even though they cannot afford to plant without outside help, feel unsympathetic toward all public-aid programs or dislike the terms of the planting program.

WHICH OWNERS ARE MOST LIKELY TO PRACTICE FORESTRY?

Those with favorable attitudes have four characteristics in common: (1) they are young, (2) they have much of their property in forest, (3) they have a relatively large woodland, and (4) they sold timber recently.1/

The younger ones.--Young people are naturally more in favor of forestry. "If I were a young man," is a frequent preface to remarks by older owners who think forestry is a good investment for someone else. Also, the younger own-

1/ These four variables were found significant for segregating owners according to attitude when tested by means of discriminant function analysis. This is a method of separating individuals or items into two classes, those with a particular attribute and those without it, on the basis of other characteristics. When tested by the same method, area in yellow pine type, area in yellow pine sawtimber stands, and percent of forest in yellow pine sawtimber stands were nonsignificant. Other factors, including distance from the owner's residence to the woodland, length of tenure, age at the time the woodland was acquired, and proportion of the woodland in yellow pine type, showed no relationship with owner attitude when examined by use of tabular comparisons and, therefore, did not appear to warrant a statistical test.

ers are more knowledgeable about forestry. This came about because it was not until after the end of World War II that strong, widespread efforts were made to promote forestry training at high schools, in veterans' classes, and for Future Farmers of America. Thus, it has reached many of the younger owners, but missed most of the older ones.

In Georgia, younger owners are more likely to be growing timber, willing to practice forestry, and practicing forestry than are older ones.2/ The chance that an individual is growing timber, as related to his age, is indicated in figure 11. The probability that an owner is willing to practice forestry is shown, by age, in figure 12. The likelihood that persons in various age classes are practicing forestry appears in figure 13.

Those who have a greater-than-average proportion of their holdings in forest land. --Especially on farms the larger the woodland relative to land in other uses, the more value this asset generally has to the owner and the higher his interest in it.

A woodland that occupies a large percent of the property may be of greater importance to its owner where agricultural land is poor than where

2/ The same probably holds true in North Carolina, but because younger owners tend to have smaller ownerships, or for other reasons, the analysis did not show it.

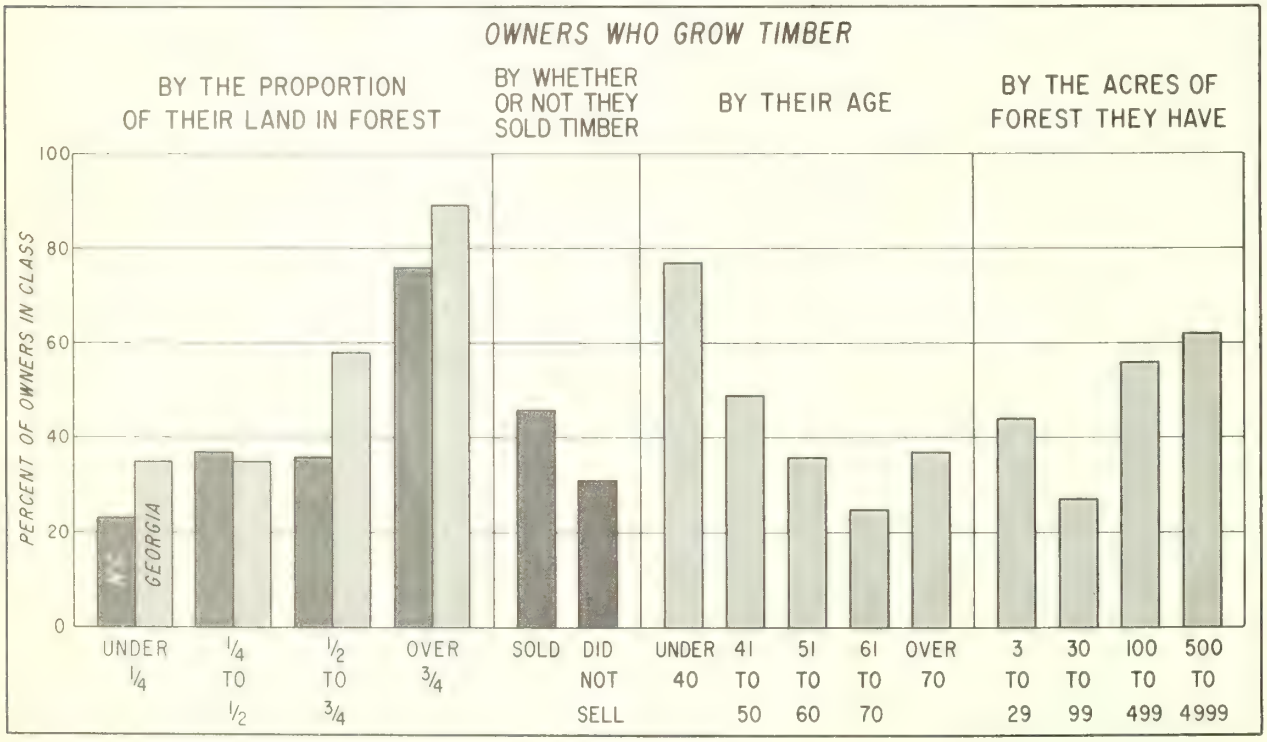


Figure 11. --Owners most likely to be growing timber in both North Carolina and Georgia are those with the greatest proportion of their property forested. In North Carolina, there is a better chance that an individual is growing timber if he made a timber sale recently. In Georgia, the percent of persons growing timber is higher among younger owners and among those with the largest forest ownerships.

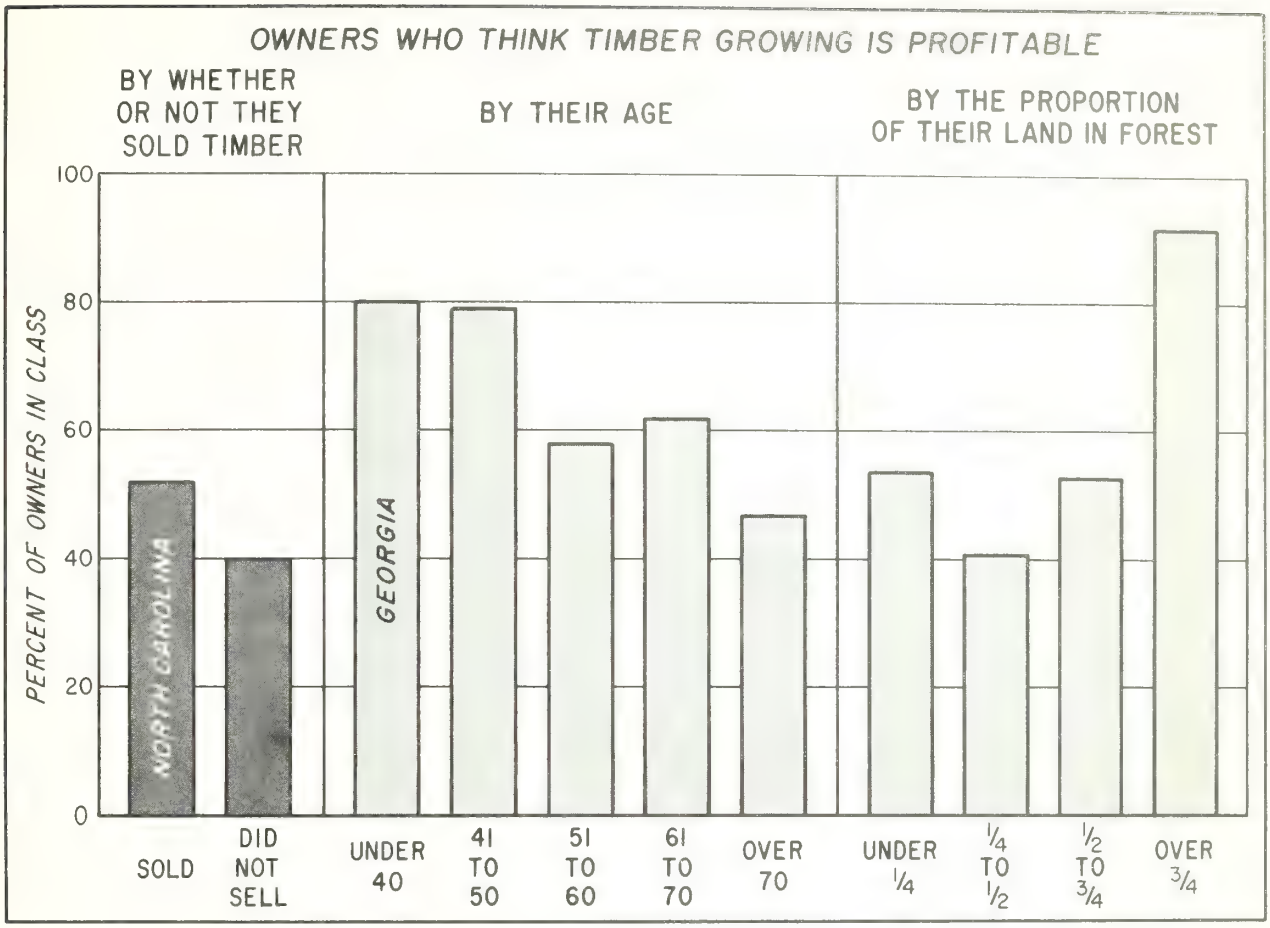


Figure 12. --The percentage of owners who think forestry would be profitable for them is highest in North Carolina among those who sold timber recently. In Georgia, on the other hand, it is highest among younger individuals and those with the greatest proportion of their property in forest.

it is fertile. This is the opinion of an owner living in such an area. He has a 450-acre farm, two-thirds of which is forested. "My farm hasn't produced a decent living for the past several years," he says, "so I've had to look to my woods." In this way he has been able to supplement his low agricultural income.

In both study areas there is a tendency for those with the greatest proportion of land in forest to consider themselves timber growers (fig. 11). Furthermore, in Georgia, these same owners are the most likely to think that forestry is profitable, and also to be practicing forestry (figures 12 and 13).

Those who have woodlands that are larger than average. --Owners are acutely aware of the economic importance of woodland size. Those with very small properties frequently make comments such as, "I don't own enough woodland to fool with." And even those whose forest acreage is about average feel that they haven't enough land to make forestry worthwhile.

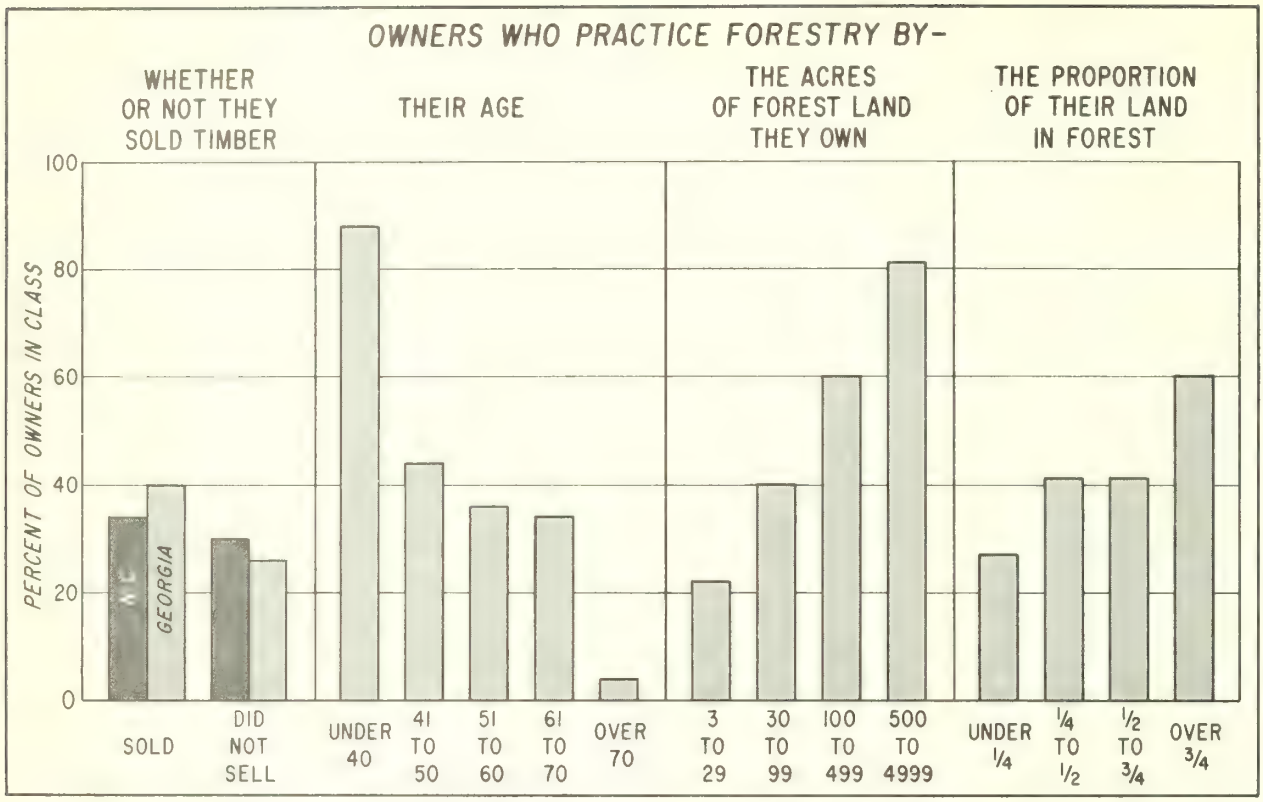


Figure 13.--In both North Carolina and Georgia, owners who recently sold timber showed a greater tendency to practice forestry than those who have not made a recent sale. In Georgia, owners more likely to practice forestry were the younger people, those with the largest forest ownerships, and those with the greatest proportion of property in forest.

In addition to having a forest enterprise of adequate size, the owner of a large forest property may actually have more wealth. The largest forest ownerships are frequently held by business and professional people and the more prosperous farmers, while the smallest properties are often in the hands of wage earners and clerks. To the extent this is the case, the largest landowners undoubtedly have more capital to invest and are under less pressure to cut prematurely.

In Georgia, those who own the greatest acreage of forest land are the most likely to be growing timber and practicing forestry (figures 11 and 13). This is not true in North Carolina. Here, ownerships are smaller and less variable in size, which may account for the difference.

Those who sold timber recently.--In North Carolina, those who sold timber during the past ten years are usually the ones who are growing timber, who think it would be profitable for them to practice forestry, and who are practicing forestry (figures 11, 12, and 13). In Georgia, too, it is the timber sellers who are practicing forestry (fig. 12).

The fact they have sold timber may cause some owners to classify themselves as timber growers. Earning a return from their woods may make others think that forestry is profitable, and encourage still others to invest in forestry. Possibly, the act of selling timber not only helps these individuals realize that forestry is profitable, but also provides them with capital to invest.

Another way in which making a timber sale may influence owner attitude is by bringing the seller into contact with forestry-minded people. This is one way, for example, in which owners learn about public programs.

WHAT THIS SURVEY SHOWS

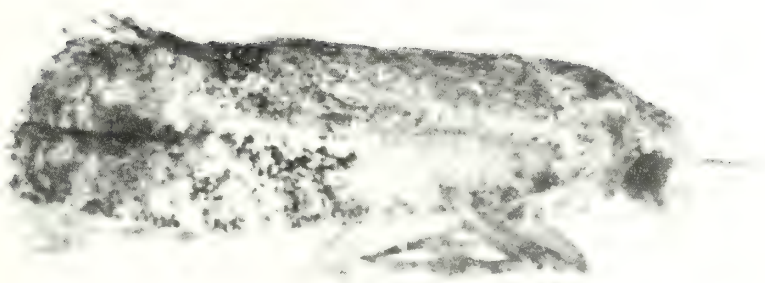
Interest in forestry appears to be associated with certain personal characteristics of the owners and the attributes of their woodlands. These are: (1) the age of the owner, (2) the proportion of his land that is forested, (3) the size of his woodland, and (4) the fact he has or has not sold timber.

Perhaps these findings could be utilized in attacking the small-forest-landowner problem. This could be done by concentrating forestry educational and assistance efforts on those persons who would probably respond favorably. Any of the above four characteristics would serve to identify such individuals. However, the factor, "sold timber recently," may be the best one to use, since in both study areas it indicates those persons most likely to be practicing forestry.

THE NANTUCKET PINE MOTH

A Literature Review

by
Harry
O.
Yates III



Station Paper No. 115

December 1960

U.S. DEPARTMENT OF AGRICULTURE
FOREST SERVICE
Southeastern Forest Experiment Station
Asheville, North Carolina

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THE NANTUCKET PINE MOTH *Rhyacionia frustrana (Comst.);* A LITERATURE REVIEW

by

Harry O. Yates III [1]

Southeastern Forest Experiment Station

INTRODUCTION

With the establishment of large areas of pine plantations, the Nantucket pine moth (*Rhyacionia frustrana* (Comst.)) has become more and more abundant and has caused greater and greater concern. Paradoxically, this concern for the most part is confused by the large amount of conjecture about the damage this insect actually inflicts.

Some researchers contend that damage inflicted by the Nantucket pine moth is transitory, representing only a temporary loss of height growth, and that control efforts are not warranted. Most published material does not support this contention. For example, Korstian and Maughan (*30*) had this to say: "Present indications are that the net result will mainly be the lengthening of the rotation by approximately five years, although it is too early to formulate definite conclusions."

At the present time research is being conducted on various phases of this problem by all the United States Forest Service Experiment Stations whose territory includes areas where the Nantucket pine moth is found. In addition, several state agricultural experiment stations and universities are engaged in similar research programs. There appears to be no practical method at the present time for the control of this insect on a large scale. For this reason, much work has yet to be done before the Nantucket pine moth problem is solved. This paper is an attempt to bring together the past and current work being done on this forest insect.

[1] In cooperation with the Georgia Forest Research Council and the Georgia Forestry Commission.

NOMENCLATURE

The Nantucket pine moth is a small lepidopterous insect belonging to the genus *Rhyacionia* of the family Olethreutidae. Synonymy for the Nantucket pine moth include the following: Comstock first described the species and assigned the name *Retinia frustrana* Comstock. In 1903 Fernald reclassified it as *Evetria frustrana.* In 1923 Heinrich (*24*) revised the classification of the North American moths of the subfamily Eucosminae of the family Olethreutidae. He retained the specific name and placed this species in the genus *Rhyacionia.*

The presently accepted common name for this insect is the Nantucket pine moth. The term "tip moth" is commonly used to apply to members of the genus *Rhyacionia* and closely related moths that inflict similar damage to host trees. For simplicity, the Nantucket pine moth will frequently be referred to throughout this paper as "tip moth."

Presently there are ten species of *Rhyacionia* known to exist in the United States. All have the same general habits and inflict injury by boring into buds and young stems of various pines. *Rhyacionia buoliana* (Schiff.) is the only species not native to this country. This European pine shoot moth, as it is commonly known, was first discovered in the United States in 1914.

Studies on the Nantucket pine moth have undoubtedly been made more difficult by the presence of various members of the genus *Rhyacionia* being found in association with *R. frustrana.* It is quite likely that these various species have been confused with the Nantucket pine moth in the reporting of some literature, because *R. buoliana*

(Schiff.), *R. busckana* Hein., *R. adana* Hein., and *R. rigidana* (Fernald) are all species of *Rhyacionia* known to occur within the Nantucket pine moth's range. The remaining five species, including *R. frustrana* var. *bushnelli* (Busck), are found in the western and midwestern parts of the United States.

In 1910, Swenk began observations of a pine tip moth injuring plantations in the Nebraska National Forest. Four years later Busck described this moth as a separate western species distinct from the eastern *frustrana* and gave it the species name *bushnelli.* Later, after several years of controlled rearing of *frustrana,* Heinrich succeeded in producing a typical *bushnelli.* This was done by inducing the smaller *frustrana* to oviposit on western yellow pine (*Pinus ponderosa* var. *ponderosa*). After rearing the insect on this tree, a comparison of the genitalia of several specimens convinced Heinrich that *bushnelli* was merely a local food plant race. He also states that there are no consistent characters upon which to separate the two. Busck's original name, *bushnelli,* was retained as a racial designation because of the great economic importance in some sections. The outstanding difference between this variety and *R. frustrana,* other than the range and larger adult size, is the overwintering habit. The *bushnelli* variety, prior to pupation in the fall, drops to the ground and pupates in the litter; the Nantucket pine moth overwinters in the young shoots of the host tree.

Literature referring to both *R. frustrana* and *R. frustrana* var. *bushnelli,* because of their similarities in habit and damage, is considered in this review.

DISTRIBUTION

Drawing on information from the National collection of the American Museum (Smithsonian Institution), Heinrich (*24*) found the tip moth distributed in Florida, Texas, Georgia, Alabama, South Carolina, West Virginia, Virginia, Pennsylvania, District of Columbia, New Jersey, and Massachusetts. Since Heinrich released this list, the species has been reported from North Carolina, Louisiana, Oklahoma, Mississippi, Arkansas, Tennessee, Ohio, Kentucky, Missouri, Illinois, Indiana, New York, Delaware, Maryland, Connecticut, and Rhode Island. Susceptible species of pine planted in any of these states are subject to tip moth attack. More generally this might include the range of shortleaf (*P. echinata* Mill.) and loblolly pine (*P. taeda* L.) in the South and the range of Virginia (*P. virginiana* Mill.) and pitch pines (*P. rigida* Mill.) in the Central and Northeastern states.

The Nantucket pine moth has been reported at Berthierville, Quebec (*15*). In 1942, however, Brown (*8*) indicated that this insect was misidentified and in reality was the white-pine shoot borer, *Eucosma gloriola* Hein. An undisputed record of Canadian occurrence indicates that the Nantucket pine moth was found in Simcoe County, Ontario, in 1944 (*38*). In this case, only a small population was found, but this report does indicate that the range of the insect extends into Canada. In all probability these are small populations restricted to the southern portions of Canada.

Bronson found through correspondence that this insect is not known to occur in northern New York, Vermont, New Hampshire, or Maine.[2] In view of the preceding Canadian report, the moth in all probability may be found in these states. Scarcity of suitable host material and cold weather undoubtedly limits the spread and reduces the population to a low level (fig. 1).

R. frustrana var. *bushnelli* has been recorded in Arizona, New Mexico, and Nebraska (*24*), in Minnesota, North and South Dakota (*10*), and, most recently, in Montana (*3*). It is believed that infestations located in Arizona and New Mexico were probably introduced on nursery stock coming from Nebraska.

HOSTS

Throughout the geographic range of the Nantucket pine moth there appears to be only one or two species of the genus *Pinus* not attacked by this insect. There is no record of attack on eastern white pine (*P. strobus* L.) or on longleaf pine (*P. palustris* Mill.). Two records of attack resembling tip moth damage on longleaf pine have been reported; however, these were not verified by collection and identification of the insect (*53*). For several years Wakeley carefully examined longleaf pine for tip moth injury but was never able to positively identify such damage.

Slash pine (*P. elliottii* var. *elliottii*) appears to share some of longleaf pine's resistance to attack by this insect (fig. 2). When attack does occur, it is usually restricted to the buds and generally creates very little injury, if any, to the developing shoots. Large amounts of resin accumulate on the outside of slash pine shoots where larval feeding

[2] Bronson, A. H. The Nantucket pine tip moth (*Rhyacionia frustrana* Comst.) and its occurrence on the Duke Forest. 1941. (Unpublished master's thesis. Copy on file Forestry Dept., Duke Univ., Durham, N. C.)

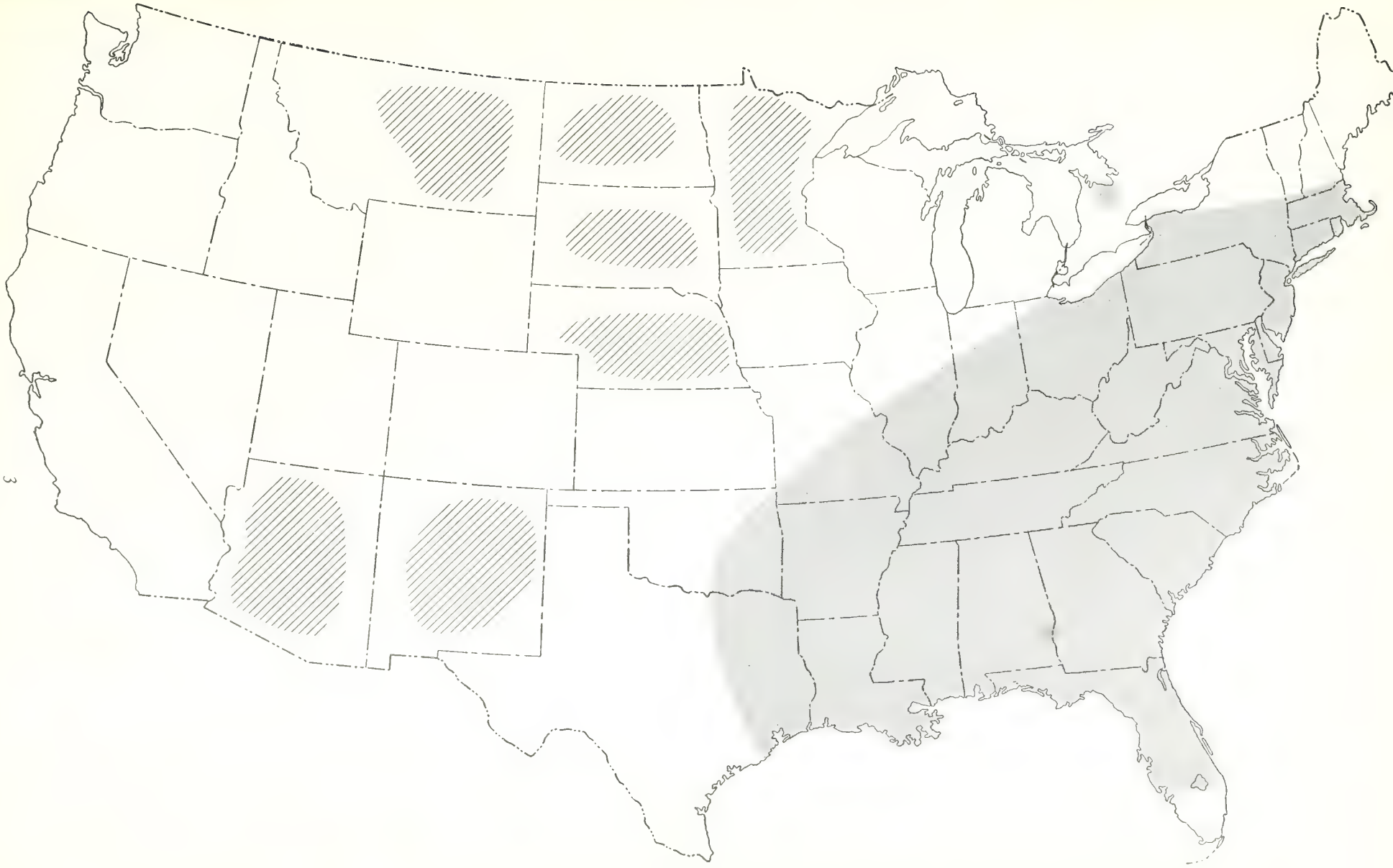

Figure 1.--Shaded area shows the general distribution of the Nantucket pine moth. Canadian observation is indicated by shaded circle. Cross-hatching shows states in which the bushnelli variety reportedly occurs.

Figure 2.--Severely injured loblolly pine growing adjacent to slash pine completely free of tip moth injury.

has occurred. Wakeley (*54*) states, "There may be a direct relation between the free resin flow of slash and longleaf pines and their resistance to tip moth attack." This free resin flow, along with the larger diameter of developing shoots in longleaf and slash pines compared with the smaller diameter of the heavily attacked species like loblolly pine and shortleaf pine, may very well be responsible for the difference in susceptibility and resulting injury. Although slash pine is generally not seriously attacked by the Nantucket pine moth, reports from Alabama in 1954 (*43*) indicated that approximately 1,000 slash pine were heavily infested. Such reports of heavy tip moth damage to slash pine plantations are not uncommon, but infestations are by far the exception rather than the rule.

Wakeley (*52*) has reported Nantucket pine moth attack on loblolly pine, shortleaf pine, ponderosa pine, Monterey pine (*P. radiata* D. Don), slash pine, sand pine (*P. clausa* (Chapm.) Vasey), spruce pine (*P. glabra* Walt.), and Sonderegger pine (*P. Xsondereggeri* H. H. Chapm.). This last species is a hybrid of longleaf pine and loblolly pine and is frequently damaged as seriously as its loblolly pine parent. Smith et al. (*42*) found pitch pine, Austrian pine (*P. nigra* Arnold), jack pine (*P. banksiana* Lamb.), ponderosa pine, and Scotch pine (*P. sylvestris* L.) all heavily infested in a Pennsylvania state nursery. Other reports include Japanese red pine (*P. densiflora* Sieb. and Zucc.), Japanese black pine (*P. thunbergii* Parl.), lodgepole pine (*P. contorta* Dougl.), Virginia pine, red pine (*P. resinosa* Ait.), and pond pine (*P. serotina* Michx.).

All species listed are subject to attack in varying degrees, but certain hosts are preferred in different parts of the United States. In the South and Southeast the favored hosts, by far, are loblolly and shortleaf pine. When both species are grown adjacent to each other they receive the same relative incidence of attack, but shortleaf pine appears to be the more seriously injured of the two species. Pitch pine, Virginia pine, and Scotch pine appear to be favored in New England and the Middle Atlantic States. In Nebraska the local food plant variety favors ponderosa pine and red pine over other species (*20*).

DESCRIPTION

The following descriptions do not go into any of the taxonomic details of these insect forms. They merely describe the insect in a general way to indicate size and appearance. More detailed descriptions of these forms can be found in the following publications: *17, 24, 33,* and *41.*

Adults

The adult moths are quite inconspicuous when at rest on foliage because of their small size. The wings are folded over the abdomen when the insect is not in flight; extended, the total wing span is 9 to 15 mm. At first glance, the adults are rather drab, but by closer examination the colorful details can be observed. The head, body, and appendages are covered with gray scales with the exception of the irregular brick-red and copper-colored patches on the forewings. These patches are separated by irregular bands of gray scales (fig. 3).

Sexual difference of the adults is readily determined by observation of the abdomen. The female abdomen is swollen in the middle and is apically pointed; the sides of the male abdomen are subparallel with a truncate apex. The inspection of the abdomen is quite reliable to determine sex of individual moths.

Figure 3.--Adult male Nantucket pine moth.

Both *R. frustrana* and *R. rigidana* are very often found occurring together in the field. Determination of the difference between the adults of these two species is very difficult. In general *R. rigidana* is a larger moth (18 mm. wing span), but reliable identification can be accomplished only by dissection.[3]

Eggs

Eggs are elliptical and measure approximately 0.85 mm. by 0.55 mm. When laid they are opaque and whitish, and in several days turn yellow to medium orange. Prior to hatching, they turn grayish. At this time the dark head capsule and the slight movements of the developing larva can be seen through the egg chorion. Eggs are generally laid singly; however, groups of two or three eggs are sometimes encountered (fig. 4).

Larvae

The first instar larvae are very tiny, cream-colored caterpillars approximately 1.5 mm. long. The head and thoracic shield are black. The body is sparsely covered with minute hairs that are barely visible even under a hand lens. The last instar larvae are light brown to orange in color and grow to approximately 8 mm. in length.

Two workers have attempted to determine the number of larval instars this insect passes through. Mortimer (*34*) was unable to distinguish more than two instars, but stated that a third may possibly occur after the larvae have tunneled into the shoot. Actual head capsule measurement of the *bushnelli* variety indicated six groups (*19*). Although these exhibited much variation, which was attributed as possibly a result of food source, they concluded that this insect went through a series of six instars. Variations of measurement in the past might well be caused by any one, or a combination, of the following: differences in food source, difference in sex, or different species of *Rhyacionia* all thought to be *frustrana*. In any event, more than three instars occur.

Except for the crochets possibly being slightly more numerous on *R. rigidana*, there are no satisfactory characters to separate the larvae from *R. frustrana* (*33*).

Pupae

Pupae are approximately 6 mm. in length. When first formed they are light brown in color and become darker as they mature. Just prior to emergence of the adults, variations in the wing coloration can be detected through the pupal skin.

The female pupae are reported to have the two genital openings confluent on the eighth abdominal segment, whereas the single male genital opening is situated on the ninth segment.[4]

[3] Clarke, J. F. G. Personal correspondence. U. S. Natl. Mus. 1959.

[4] Bronson, *op. cit.*

Figure 4A.--Series of five tip moth eggs laid on loblolly pine shoot by caged adult.

Figure 4B.--Tip moth eggs laid on developing loblolly pine shoot.

LIFE HISTORY

Life Cycle

The Nantucket pine moth spends the winter months as a pupa within the injured tips (fig. 5). (One early reference indicates a full grown larva was found during February, indicating possible occasional larval hibernation (*9*).) In Nebraska, the mature larva of the *bushnelli* variety drops to the ground and overwinters as a pupa in the litter (*19, 49*). Such a habit possibly accounts for the survival of these overwintering forms during the cold winter months experienced in this area.

On warm, sunny days in early spring, adults begin to emerge from the tips. In the southern part of the United States, adults can be found in the field as early as January. By circular movements of the abdomen and with the aid of a series of abdominal spines, pupae are able to work part way out of the infested tips. Here the adult is free to emerge without injury and leaves the empty pupal case projecting from the tip.

The preoviposition period is considered to be short. It is during the hours of dusk and darkness that mating and egg laying occur. Mortimer reports that during the evening the moths fly around the trees depositing their eggs, and that eggs were found in most instances 2 days after adults had emerged (*34*). These eggs may be found on the new or old growth needles, the developing tips, or on the buds. In Virginia (*50*) it was found that a majority of the eggs were laid in the axils of the needle and the stem.

Egg incubation varies with weather conditions. It is particularly affected in the spring when cool weather is apt to occur after egg deposition. Such a condition would cause prolonged incubation. In Tennessee, the first spring generation egg period has been recorded as long as 31 days (*34*). During this time the weather was cool and damp. The second and third generation egg periods for the

Figure 5.--Injured loblolly pine shoot dissected to expose overwintering pupae.

above mentioned season were 18 and 9 days, respectively. At Durham, North Carolina, during the spring of 1941, first generation eggs hatched in about 2 weeks.[5]

The developed larva chews its way out of the egg, leaving the egg chorion still secured to the plant. The first instar larva begins to migrate about the shoots looking for a suitable place to feed. Shortly, a delicate web is constructed in the axil formed by a developing needle and the stem. At first, evidence of the presence of tip moth larvae on developing shoots is quite unnoticeable. The small webs constructed by the young larvae can only be detected by close inspection of individual shoots or buds. Here the larva bores into the needle sheath and feeds on the needles. Early injury may consist of only one dead needle which has been severed by the feeding of the larva in the sheath of the needle fascicle. In addition, some external feeding on the stem occurs.

[5] Bronson, *op. cit.*

Mortimer (*34*) found that during the second instar the larva spins a new and larger cell-like web between buds or the buds and needles. After consuming this bud, the larva migrates to other buds on that shoot or moves to entirely new shoots. Recent unpublished studies by other workers confirm larval migrations; most older publications indicate that the larvae begin boring into the shoots or buds almost immediately and carry out no such extensive migrations about the host plant.

As the insect develops, fecal material and resin exuded from these lesions begin to accumulate on the outside of the tips. Eventually the mining of the larvae severs the conductive tissue of the tip and the affected portions turn brown. This browning is quite conspicuous at considerable distance. In many cases it is the first evidence of injury noticed by the untrained observer.

Larvae generally continue feeding within the shoots and buds once they have begun boring into these tissues. The succulent bud appears to be the most attractive portion of the shoots. Once this has been consumed, larvae begin boring down the center of the young stem. It is not uncommon to find more than one larva feeding in a single stem. In the case of heavy infestations this might run as high as 10 larvae. The entire larval period lasts 2 to 4 weeks. Prior to pupation, a webbed cell is constructed within the injured shoot.

Generations Per Year

A series of experiments were conducted during 1929-1930 to establish whether the tip moth had overlapping broods in the South or went through successive generations (*54*). Evidence indicated successive generations. Depending on the geographic location, the life cycle is known to be repeated one to four times during the growing season. However, recent work indicates that in the extreme South there may be as many as five generations during this period. Possibly a sixth generation might occur in some sections during a very favorable season.

Wakeley reports (*54*) that there are four successive generations per year on young pines of susceptible species in southeastern Louisiana. This appears to hold true for most of Texas, Oklahoma, Mississippi, Alabama, Georgia, and Florida. The southern portions of the Gulf States may very well experience more than four generations per year. Areas in North Carolina,[6] Tennessee (*34*), and Virginia (*50*) are reported to have

[6] Bronson, *op. cit.*

three generations; two generations are reported in Ohio (*37*) and Pennsylvania (*42*). This also applies to the areas north of these two states. A number of workers studying the tip moth have recorded the adult emergence periods (fig. 6).

DAMAGE

Damage caused by the Nantucket pine moth can be regarded in four categories: deformation of the host tree, loss or retardation of height growth, reduction of cone crops, and in severe instances, mortality of infested trees (fig. 7).

Tree Deformation

The ability of the trees to recover from terminal injury without any serious crooking is dependent on the production of new buds from needle bundles as well as the vigor of the tree. In general, the more prolific the tree is in producing such buds, the better its recovery from tip moth attack.

Where tree vigor is sufficient, new buds are produced, and attacked trees readily recover. Where tree vigor is insufficient or where the leading shoots are continually attacked by tip moths, all of the uppermost lateral branches may compete for dominance and cause a multiple- or crooked-stemmed tree. In some cases recovery of trees from insect attack results in a crooked rather than a straight stem. This ability of attacked trees to make a good recovery may be an inherited characteristic.

Loss or Retardation of Height Growth

At present no one is able to give more than an estimate of the final effect of tip moth damage on the host tree. Past study indicates that significant difference in height growth occurs between protected and unprotected trees during the early years of growth. Yet, what is not known is how much difference will exist when the trees are of a merchantable size. Such knowledge would indicate to what extent control operations were economically feasible.

Site appears to influence to a great extent the severity of damage tip moth inflicts on the host trees. Generally, the better suited a tree species is to the site, the less severe the injury. Wakeley observed (*53*) that loblolly pine planted on sites best suited for longleaf pine were so seriously killed back by tip moth that they were overtaken by

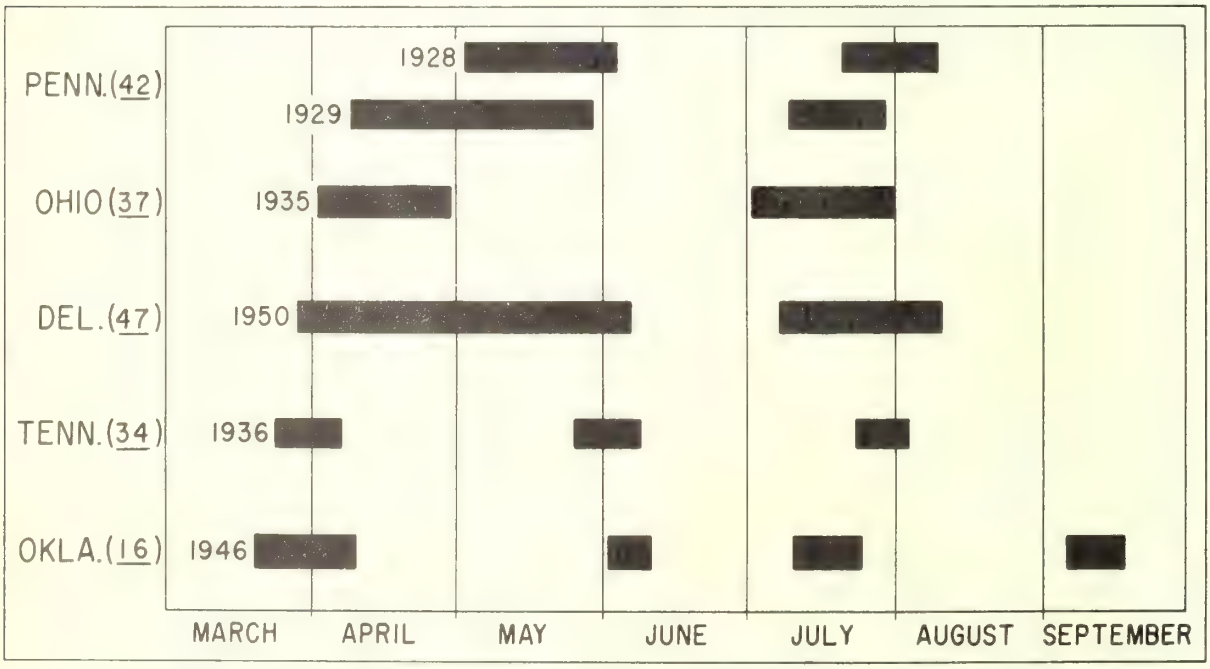

Figure 6.--Adult emergence periods as reported by various investigators for different states. These emergence periods illustrate in most cases only one season and may vary from year to year, depending on local weather conditions. Horizontal lines show span of the adult emergence for year indicated.

Figure 7A.--Crooking of the main stem of a loblolly pine caused by the repeated attack of tip moth.

Figure 7B.--Forking of the main stem of a loblolly pine caused by tip moth attack of the terminal leader.

Figure 7C.--Young shortleaf pine shoot with female flower that has been attacked by tip moth. Initial attack has caused bending of the growing shoot. Subsequent feeding will sever the conductive tissue and cause death of the shoot and female flower.

Figure 7D.--Young loblolly pine killed by severe and repeated attack by tip moth.

natural longleaf reproduction in 10 years. On deeper and more penetrable soils, possibly only a few feet away, the loblolly made much better growth in spite of tip moth attack. The influence of site on the severity of tip moth damage can also be observed along the sides of roads and highways. Road grading and the action of erosion have in some cases completely removed topsoil and left bare mineral soil. Reproduction found growing in these areas is very often so severely damaged annually that death results (fig. 8).

Two types of injury were located on trees infested with tip moth in Pennsylvania (*42*). "On host species having large buds and heavy growth, the injury is confined to the buds, while on species with small buds and weak growth the tips of the twigs as well as the buds are hollowed out." This same observation may be made between slash pine and loblolly pine in the South. Slash pine, when attacked, generally sustains injury to the buds and only when severely attacked are the terminal shoots injured. Loblolly pine, on the other hand, commonly has the shoots as well as the buds completely mined out.

The effect of repeated attacks on the growth and dominance of loblolly pine seedlings was measured on released trees in North Carolina (*55*). On the basis of the number of years a seedling was attacked, it was found that each year of attack reduced seedling growth by 0.5 foot for three successive years.

Merkel in 1955[7] and Mason in 1958[8] both reported on the effects of tip moth on growth loss in the Southeast. Throughout the summer, various formulations of insecticides were used to control tip moth infestation on the test trees. The results Merkel received in the Piedmont of South Carolina indicated that protected trees averaged 0.43 foot greater in height than the check trees. This proved to be statistically significant, but prac-

[7] Merkel, E. P. Studies on control of the Nantucket pine moth in relation to growth loss. U. S. Forest Serv. Southeast. Forest Expt. Sta. Unpublished Preliminary Res. Note. 1955. (Mimeographed, 2 pp.)

[8] Mason, R. T. Study of tip moth effects on height growth in loblolly pine plantations: Two year results. Hiwassee Forest Res. Note 3, Calhoun, Tenn. 1958. (Mimeographed, 2 pp.)

Figure 8.--Severely damaged loblolly pines growing along badly eroded roadside.

tically speaking appeared to be small. In southeastern Tennessee, Mason found a significant difference of 0.41 foot in reduced growth on unprotected trees in 1956. However, results of the 1957 season were not significant at all; in fact, the unprotected trees grew an average of 0.08 foot more than the protected trees. A similar observation was made by Wenger (*56*) in 1955. Tip moth-infested loblolly pine seedlings showed greater height growth than uninfested seedlings. Infested 2-year-old seedlings showed growth in height of 0.32 foot more than the uninfested seedlings. A similar difference of 0.45 foot was observed with 4-year-old seedlings. Both of these differences were found to be significant, and no plausible explanation for this behavior could be advanced.

At Mississippi State College (*36*) the growth differential for protected loblolly pine was very significant. The average difference was recorded for both upland and bottom land sites and amounted to 12.4 inches and 20.9 inches, respectively. Terminal attack was completely controlled on the treated trees by spraying six times during the growing season at intervals of 10 days to 2 weeks. This spraying practice can hardly be recommended on any basis other than experimental, but it did demonstrate the increased growth that could be expected in these areas if tip moth were completely controlled.

Some of the height difference between 23-year-old loblolly and shortleaf pines in northern Mississippi was attributed to early tip moth damage (*57*). After 13 years growth, loblolly pine averaged 34 feet in height and shortleaf pine 23 feet in height — at the end of 23 years the average heights were 63 and 48 feet, respectively. It was observed that this insect attacked and killed back the leaders of shortleaf far more severely than those of loblolly.

The repeated killing of the growing shoots by each successive generation of this insect is believed by some workers to significantly cut down the growth of the injured tree (fig. 9). Although limited studies of 1 to 2 years have been conducted, no one has yet proven the over-all effect of tip moth attack over a long period of time. In the fall of 1958, the Southern Forest Experiment Station[9] started a research study to determine the over-all difference in growth between protected and unprotected trees over a 30-year period, using both loblolly and shortleaf pines.

[9] Beal, R. H., and Orr, L. W. Evaluation of tip moth injury in relation to growth of loblolly and shortleaf pine. South. Forest Expt. Sta. Work Plan. 1958. (Mimeographed, 11 pp.)

Figure 9.--Loblolly pine leader showing multiple injury by tip moth. Swollen needle fascicles just below injury, such as the ones outlined in white, are new buds developing.

At the completion of the study it is hoped that this basic question "Just how much damage does tip moth actually cause?" will be answered. At present this question will receive a variety of answers from persons who have worked with the insect. These will include the extremes of "no damage" to "increasing the rotation by five or more years." It must be remembered that the degree of tip moth damage in one area is not necessarily the same as the degree of damage occurring elsewhere. This also applies to different species of trees which are attacked with different degrees of severity. Therefore, such divergent answers are undoubtedly valid when they are applied to certain areas.

Reduction of Cone Crops

The increasing need for good quality forest tree seeds has stimulated the development of seed orchards in many areas. These open-grown seed orchards provide ideal conditions for tip moth development. When trees are first set out in fields, tip moth damage may very well affect early survival. Zak (*58*) states that tip moth injury in seed orchards may, after the first or second year, promote the desirable characteristic of a full and bushy crown. When the trees begin producing cones, however, attack may prove to be a hindrance and reduce seed yields by destroying terminal buds containing embryonic flower buds. Another point to be considered is the availability of suitable grafting tips. It is highly desirable that undamaged tips are available for grafting of the superior scions to stock trees.

Tip moth attack is generally restricted to pines less than 15 feet in height. Many accounts, however, have reported trees of much larger size being attacked. Such tip moth injury could be responsible for the reduction of cone crops on mature trees.

In 1957 (*45*), parts of northern Mississippi, Louisiana, and Texas reported severe infestation of tip moth on commercial size trees. From the air the red-fringed crowns appeared dead, as if killed by bark beetles. This attack is not always as easily recognized on large trees. In most cases only scattered tips are attacked and recognition of this injury from the ground requires careful observation.

Tree Mortality

Possibly the most serious damage caused by the Nantucket pine moth ever reported was in 1876 when the presence of the insect was first recorded. Scudder (*41*) observed large numbers of 20- to 30-year-old pitch pines on Nantucket Island that were dead and dying of an unknown cause. During the War of 1812, the inhabitants of Nantucket Island, in an effort to obtain an adequate fuel supply, had denuded the island of every tree. For many years following, the island remained barren. Finally, plantations of pitch pine were set out to reforest the area. Mortality began to appear when the trees were 10 to 20 feet tall (*39*). Examination of these trees led Scudder to believe that mortality was caused by a terminal-feeding Lepidoptera, later named the Nantucket pine moth. This is the only reference in the literature that reports widespread killing caused by *R. frustrana*.[10]

There are other reports of possible tree mortality as a result of tip moth attack (*19, 21, 34, 44*); however, when killing occurs, it is usually restricted to trees growing on very poor sites. In these cases possibly the site condition contributes as much to the death of the tree as the insect. In western Florida, severe tip moth infestations caused high mortality of Monterey pine the second and third years after planting. Although adjacent native pines were also heavily attacked, they demonstrated a capacity to survive (*44*).

CONTROL

Scudder, in 1883 (*41*), suggested three controls for the tip moth on Nantucket Island. They inincluded building bonfires at night to kill egg-laden adults attracted to the light, and the collection and burning of all infested tips on the island. (Although many references mention the practice of hand picking infested tips for control of tip moth, the Great Southern Lumber Company in Louisiana gave up such a control operation after two seasons of unsuccessful attempts (*54*).) Scudder's third proposal was to cut down every tree and seedling on the island to eliminate the food source of the insect!

Chemical Control

Most of the early chemical control work on the Nantucket pine moth was influenced by control work on the introduced European pine shoot moth. Howard (*26*) reported in 1925 that a 2-percent nicotine dust was very effective in killing the adults of the *bushnelli* variety of tip moth. In 1936 Baumhofer (*5*) reported on the prevention of tip moth introduction from nursery stock into isolated plantations. He advocated dipping 2-year-old seedlings in formulations of both white oil emulsion and nicotine oleate for consistent kills of the eggs without any injury to the trees. This treatment was not effective against seedlings that contained larvae or overwintering pupae within the tips. It was recommended that injured seedlings that contained larvae or pupae in the tips

[10] In view of the absence of such widespread mortality since this first report, there is some question that the Nantucket pine moth was the major factor causing this mortality. It is conceivable that low winter temperatures or salt spray could have caused severe weakening of these exposed trees and been the primary factor responsible for mortality.

should be cut off one inch below the injured portion. Both dipping and cutting off the injured tips were considered necessary when eggs, larvae, or pupae were apt to be present on the seedlings.

During the middle and late forties DDT became available for experimental use. This led the list in the development of the great number of organic insecticidal compounds now available. In 1946, DDT was tested for the control of tip moth in Oklahoma (*2, 16*), and formulations as low as 0.118-percent DDT were found to be effective. Infestation in sprayed plots averaged 9 percent compared to 74 percent in the check plots.

In Delaware, Stearns (*47*) worked on a chemical control for both the Nantucket and European tip moths. This task was complicated by two emergence periods for the Nantucket pine moth and one emergence period for the European pine shoot moth. Blackleaf 40, lead arsenate, BHC, parathion, and DDT in various formulations were all tested. Parathion and DDT were the only insecticides that gave reliable control of both species. The final recommendation called for a spray at each peak emergence, and one 14 days prior to, and one 14 days following emergence. This schedule necessitated a total of nine different sprays during a single season.

In 1955, one percent DDT or one percent BHC, formulated in either emulsions or suspensions, were the only insecticides that gave nearly 100 percent protection from tip moth at Union, South Carolina.[11]

Tip moth is prevalent in forest tree nurseries. To cut down the loss of shippable seedlings and prevent the distribution of infested nursery stock in Virginia,[12] tests were conducted using periodic applications of DDT at the rate of 1 pound per acre. Tip moth infestation was reduced to less than one in five thousand seedlings with the correct timing of three spray applications during the growing season. Because of the small size of developing seedlings in Virginia nurseries, tip moth was not found to attack prior to August.

Where control of tip moth has been unsuccessful on nursery stock, fumigation offers some possibility in preventing the distribution of the insect. Fumigation with 5 ounces of sodium cyanide per thousand cubic feet of space for a period of 1 hour has given satisfactory results (*6*).

One of the big objections to chemical control of tip moth is the problem of getting into plantations with spraying equipment. Aerial spraying would eliminate this difficulty. However, Stearns (*47*) states that results of aerial application of DDT in 1949 could only be described as most disappointing. This aerial treatment had no measurable effect on tip moth populations in an 11-year-old loblolly pine plantation.

Recent efforts have been more successful in obtaining control by this method. In 1958, aerial spray tests were conducted in both Mississippi (*36*) and east Texas (*7, 46*) by separate workers. Both operations were timed to coincide with the peak emergence of the adult moth. The east Texas operation was aimed at killing the moths, and it appeared that adult mortality was adequately accomplished. Workers in the area prior to spraying observed numerous moths flying about the plantation, but following spraying no moths could be found in flight. Both DDT and chlordane were applied at the per acre rate of 2.5 pounds actual material in 2.5 gallons of fuel oil and 5 pounds actual material in 5 gallons of fuel oil. Only DDT demonstrated any effective control. As a result of this one spray application in the spring, the DDT-sprayed loblolly pines grew in height nearly three times as much as the check trees. In spite of good control during the first generation (0 and 2 percent leader infestation for the two rates of aerially applied DDT), leaders were over 90 percent infested by the following October on these two areas. Such a rapid increase of the insect during the remainder of the summer season can be attributed to either migration into the area or a very high biotic potential.

In Mississippi (*36*), DDT, malathion, and guthion were all applied from the air as well as by mist blower from the ground. These were applied using 3 gallons of water emulsion per acre at 2, 1.5, and 0.5 pounds actual material per acre, respectively. The results of the April and June spray operations showed no significant difference between treatments. The third application in July indicated that the treated areas were significantly better than the check area. This difference was attributed to two factors. Heavy rains following the April and June applications may have been responsible for washing away the residual spray on the trees. No such rains occurred after the July application. Another factor might have been the application of the July spray at a later time after peak emergence of the adults.

Timing of insecticide sprays is of utmost importance to obtain an effective kill. Because the spray in most cases is directed at the larvae, the most desirable time for spraying is when the

[11] Merkel, *op. cit.*

[12] Morris, C. L. Chemical control of Nantucket pine tip moth (*Rhyacionia frustrana*) in forest nursery stock. Va. Div. Forestry. 1956. (Typewritten report, 5 pp.)

developing larvae chew their way out of the egg chorion and migrate to a suitable place for feeding.

Insecticidal control of the tip moth has been quite effective using such compounds as DDT and BHC, but the need for two to four applications per year and the inaccessibility of areas to spraying equipment makes such controls far from economical on a commercial basis. Results from airplane spraying in the past have been inconsistent, though the method appears promising and is still being tested by various workers. The development of new insecticides possessing longer residual characteristics and of systemic insecticides provides new compounds that might well be adapted to aerial application. Because of the high application cost and the rapid build-up of this insect, spray treatment with insecticides is presently not recommended for control of tip moth in plantations except where high value trees are involved.

Silvicultural Control

The ultimate goal of forest insect research should be the control of obnoxious insects through forest management practices. Past observations indicate that tip moth damage in natural regeneration is slight with a low incidence of occurrence. Yet, when plantations of favored host trees are established, incidence of tip moth in most cases is very high and causes varying degrees of damage. Presently all the factors involved in these observations are not known or thoroughly understood.

In spite of the great interest in silvicultural control, comparatively little work has been conducted in this field. Investigators who advocate silvicultural practices to control other insects, such as the white pine weevil, have studied the effect of various cultural practices on weevil incidence. These include spacing studies, the use of mixed stands, shading, and the planting of less susceptible species in high risk areas. With more intensive forest practice and the limitations of insecticides against this insect, interest is being shown in this field. It is very likely that more work in this direction will be carried out in the future and less effort will be made to control tip moth in plantations through the use of chemical insecticides.

A comparison of tip moth infestation in the upper and lower branches has been made by several workers. Results indicate that tip moth incidence on the upper half of trees was much higher than on the lower half of the tree. One conclusion was that perhaps the grass level acted as a protective barrier. Beal et al. (*6*) states that grasses, such as broomsedge, may offer some protection to young seedlings and the lower portions of the larger size classes of reproduction. This also was proposed as a possible explanation for the comparative freedom from attack of young pines in the Nebraska National Forest (*19*). Another explanation might be that the more succulent shoots, apparently favored by the tip moth, are found on the upper branches of the trees.

Wakeley (*54*) states that there is definite evidence that growing trees in dense stands minimizes tip moth damage. This was demonstrated by a spacing study in Louisiana which revealed that tip moth attack is more intense at the wider spacings (*22*). The beliefs that grasses offer some protection from tip moth and that moth incidence is less at the closer spacings seem to indicate that shading might be a very important factor affecting tip moth attack. Harrington (*23*), however, concluded from work done in Texas with loblolly pine that tip moth incidence was not significantly related to shading.

Another study indicated that incidence of tip moth attack was 74 percent for loblolly pine reproduction released from hardwood cover as compared to 64 percent attack for control seedlings (*55*). This overhead release apparently exposed the trees to more frequent attack. Huckenpahler (*28*) found loblolly pine the best species in northern Mississippi, despite tip moth and pine webworm attack. Tip moth attack of loblolly pine in this area was 82 percent on released and 28 percent on the unreleased stands. This same worker found that tip moth incidence among pines planted under deadened low-grade hardwoods on oak ridges in Mississippi was greater on the released plots than on the unreleased plots (*27*). Here again the indication is that some form of shading, either mutual or by other species of plants, significantly decreases the attack by tip moth.

In certain areas workers have resorted to substituting highly resistant tree species for species seriously damaged by tip moth. Japanese black pine has been successfully used in Oklahoma (*1*), on Nantucket Island (*29*), on Long Island (*32*), and along the North Atlantic coast. Although this species is subject to attack by tip moth, it is less susceptible to serious injury than other tree species indigenous to these areas. A similar substitution is being made in the South. Very often the highly susceptible loblolly pine is being replaced by the more resistant slash pine or longleaf pine. Where slash and longleaf pine are not suitable for planting, damage can possibly be reduced by confining the more heavily injured species, such as loblolly and shortleaf pines, to favorable sites, in mixture with resistant species, at close spacing, or started in brush.

Control Through Tree Breeding

Tree breeding appears to offer some hope in the problem of tip moth. Study of trees or races of trees which appear to recover best from tip moth attack or are apparently resistant to attack might indicate some physiological factor that creates an unfavorable condition for the insect. A characteristic to be desired in the breeding of tip moth-resistant pines is ability to grow rapidly. This is particularly true during the early years of the tree's growth. Secondly, the tree should be able to develop dormant buds readily.

It is very unlikely that a race of some susceptible species of pine, such as loblolly pine, exists that is distasteful to the tip moth. A search for variations within one species of pine has been rather disappointing. In 1954, a local geographic seed source study was started using loblolly pine seed from four areas in Louisiana and Arkansas. Crow found in 1956 (*11*) and 1958 (*12*) that percent tip moth damage was high on all seed sources and showed no significant variation. Similar data on tip moth were collected from southwide pine seed source study plantations (*25*). Although efforts thus far have been futile, the possibility still exists that a tip moth-resistant strain may be found.

Natural Control

Parasites of the Nantucket pine moth have received a great amount of attention in the past, undoubtedly prompted by the large number of parasites known to attack the tip moth. In spite of many species of parasites, both indigenous and introduced, tip moth has rarely been known to be controlled satisfactorily by these agents though varying degrees of control have been recorded. The first reference to parasitism of tip moth was published in 1883 (*41*). It mentioned three undetermined parasites that were found associated with the tip moth, but none seemed sufficiently abundant to exert a continued controlling effect.

Possibly the most classic example of the effect of parasitism occurred in the Nebraska National Forest (*13, 51*). Ponderosa pine in this area was being so severely injured that the discontinuance of planting this species was seriously considered. In 1924 an attempt was started to control the *bushnelli* variety by means of parasites. A preliminary study was made at Falls Church, Virginia, to learn what eastern species were available for introduction into the Nebraska National Forest. A total of twenty-one species of parasitic Hymenoptera and two species of parasitic Diptera were reared from a large quantity of tip moth-infested tips. In addition, a small lot of material received from Bogalusa, Louisiana, produced six species of parasitic Hymenoptera. Of the Virginia parasites liberated in 1925, only one was recovered, (*Campoplex frustranae* Cushman), but this species was so effective that the planting of ponderosa pine continued. Injury to terminal shoots in the area was reduced from 90 percent to 15 percent within 4 years after parasite introduction.

In spite of the presence of twenty-three different species of parasites, less effective control was recorded from 1930 to 1933 in the vicinity of Richmond, Virginia, where parasitism has ranged from 5 to 57 percent (*50*). In North Carolina (*6*), only slightly more than 7 percent of the overwintering pupae were parasitized. In this same area, however, as many as 40 percent of the tip moth eggs examined were parasitized by an unidentified egg parasite. In all probability it was *Trichogramma minutum* Riley, a Hymenoptera recorded by several workers as an egg parasite of tip moth.

In addition to parasites, a number of birds and predatory insects are enemies of the tip moth. It is not unusual to find birds tearing open tip moth-damaged shoots in search of the larval and pupal forms. However, birds can hardly be classified as very effective controls. Predatory insects, on the other hand, might have a great effect on tip moth populations. Unfortunately, little or no work on these predatory insects has been conducted and reported in the literature.

There are a great number of known parasites that attack the Nantucket pine moth. The following is a list of the known parasites of the genus *Rhyacionia* occurring in the United States. This is not necessarily a complete list but represents a large majority of the known species. Those preceded by an asterisk (*) have been reported as attacking the Nantucket pine moth.

Known parasites of the genus Rhyacionia compiled from the following references: 4, 13, 14, 18, 31, 35, and 40.

Order Diptera

Family Tachinidae

**Lixophaga mediocris* Ald.

**Lixophaga plumbea* Ald.

Order Hymenoptera

Family Braconidae

Macrocentrus instabilis Mues.

Orgilus obscurator (Nees)

Agathis binominata Mues.

**Agathis pini* (Mues.)

Apanteles bushnelli Mues.

**Microgaster epagoges* Gah.

**Phanerotoma rhyacioniae* Cush.

**Bracon gelechiae* Ashm.

**Bracon gemmaecola* (Cush.)

**Bracon mellitor* Say

Bracon politiventris (Cush.)

**Bracon rhyacioniae* (Mues.)

Bracon variabilis (Prov.)

Family Ichneumonidae

Scambus aplopappi (Ashm.)

**Scambus hispae* (Harr.)

**Calliephialtes comstockii* (Cress.)

Pimpla turionellae (L.)

**Itoplectis conquisitor* (Say)

Itoplectis evetriae Vier.

Itoplectis 4-cingulatus (Prov.)

**Glypta varipes* Cress.

**Campoplex frustranae* Cush.

Zaleptopygus retiniae (Cress.)

**Cremastus epagoges* Cush.

Cremastus evetriae Cush.

Cremastus interruptor Grav.

Cremastus rhyacioniae Cush.

Family Trichogrammatidae

**Trichogramma minutum* Riley

Family Eulophidae

Tetrastichus longicorpus (Gir.)

**Tetrastichus marylandensis* (Gir.)

Tetrastichus turionum (Htg.)

**Tetrastichus varicornis* (Gir.)

**Elachertus pini* Gah.

**Hyssopus rhyacioniae* Gah.

**Hyssopus thymus* Gir.

**Euderus subopacus* (Gah.)

Family Elasmidae

**Elasmus setosiscutellatus* Cwfd.

Family Encyrtidae

**Copidosoma geniculatum* (Dalm.)

Family Eupelmidae

**Eupelmus cyaniceps amicus* (Gir.)

Family Perilampidae

**Perilampus chrysopae* Cwfd.

**Perilampus fulvicornis fulvicornis* Ashm.

Perilampus tristis Mayr.

Family Pteromalidae

**Catolaccus aeneoviridis* (Gir.)

**Habrocytus thyridopterigis* How.

Family Eurytomidae

Eurytoma appendigaster (Swed.)

**Eurytoma tylodermatis* Ashm.

Family Chalcididae

**Haltichella rhyacioniae* Gah.

Haltichella xanticles (Wlkr.)

**Spilochalcis flavopicta* (Cress.)

Family Bethylidae

**Goniozus electus* Fouts

Goniozus longiceps Kief.

Goniozus longinervis Fouts

Efforts to control tip moth infestations using parasitic agents in the past have been limited to their introduction into an area. Percent parasitism has been found to vary considerably from year to year and from generation to generation. In the future, breeding large quantities of selected parasites and releasing these parasites at the most advantageous time in tip moth-infested plantations may prove less costly and more effective than chemical controls.

In 1910, Swenk (*48*) reported evidence of an entomophilous fungus that had been at work in Nebraska. Unfortunately, this is the only record of any such agent occurring naturally. As far as can be ascertained such a fungus had never been isolated or identified. However, the possibility of the presence of either a virus or bacterium that is lethal to the Nantucket pine moth is receiving much interest. This interest has been stimulated by success obtained in microbial control of other insects.

SUMMARY

The Nantucket pine moth, *Rhyacionia frustrana* (Comst.), is generally considered a major forest insect. This insect is found throughout the eastern United States; its range extends from eastern Texas and Oklahoma north to Ohio and eastward into southern New Hampshire. One report indicates the moth occurs in southern Canada. This "tip moth," as it is commonly referred to, attacks the growing shoots of almost all native and introduced pines. Longleaf pine and eastern white pine are the only species which appear to be immune to such attack.

The body and appendages of the small adult moths are covered with gray scales. Irregular brick-red and copper-colored patches appear on the forewings. In the spring of the year, the adults emerge from the overwintering pupae and lay their eggs on the buds, new needles, and developing shoots. The developing larvae bore into this growth; subsequent feeding causes death of the new growth. Pupation occurs within the dead shoot. Depending on local weather conditions, there are one to five generations each season.

Attack by the Nantucket pine moth is most severe in young plantations. Damage inflicted on the host tree can be regarded in four different categories. They include tree deformation, loss or retardation of height growth, reduction of cone crops, and in severe instances, tree death. It has been found that all four of these injuries occur in different degrees; however, the economic significance of such injuries have not yet been established.

Effective control of this insect can be accomplished by the application of insecticides by hydraulic sprayers. Some success has been obtained by aerial application. Except for high value areas, insecticidal control procedures cannot be recommended because of economic considerations. The

relatively small amount of work conducted in silvicultural control indicates that growing trees in dense stands minimizes tip moth damage. Growing susceptible pines under hardwood cover also minimizes injury. In areas where certain species are severely attacked, such trees have been replaced by species not so seriously damaged. Efforts to find highly resistant or immune trees thus far have been futile. Continued search for such trees and tree breeding may result in the discovery or development of a strain that will be highly resistant to tip moth injury. In the field of natural control, considerable work has been done on the parasites of this insect. In spite of the great number of known parasites and the fairly high percent parasitism, these agents do not appear to affect to any great extent tip moth populations and subsequent injury.

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Agriculture Asheville

Prescribed Burning For Understory Control

In loblolly pine stands of the coastal plain

FEB 1 3 1961

by

Thomas Lotti, Ralph A. Klawitter and W. P. LeGrande

Station Paper NO. 116

December 1960

Acknowledgment is due L. E. Chaiken, who was largely responsible for planning the plot studies which form the main basis for this publication; the West Virginia Pulp and Paper Company, on whose Westvaco Experimental Forest part of the plots are located; and to many others who through the years contributed to this study in one way or another.

U.S. DEPARTMENT OF AGRICULTURE
FOREST SERVICE
SOUTHEASTERN FOREST EXPERIMENT STATION
ASHEVILLE, NORTH CAROLINA

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INTRODUCTION

THE UNDERSTORY PROBLEM

If one were to select the particular problem giving pine foresters the most concern, it probably is the natural replacement of pine by the more tolerant but often inferior hardwoods. This is especially true for loblolly pine (*Pinus taeda* L.), which is the principal commercial species of the southeastern United States. (*12*). Early invaders of the understory in the loblolly pine stands of the southeastern coastal plain are mainly light-seeded species such as sweetgum (*Liquidambar styraciflua* L.), blackgum (*Nyssa sylvatica* Marsh.), red maple (*Acer rubrum* L.), and southern bayberry (*Myrica cerifera* L.). Later, the climax components, oaks (*Quercus* spp.) and hickories (*Carya* spp.), appear (*14*). In stands protected from all fires, the understory development is often rapid; where management also requires early and heavy thinning of the pine overwood, understories develop even faster. The problem becomes more acute where many large-scale harvest cuttings are made without adequate measures for regeneration of the pine. Hundreds of thousands of acres of former pine lands now converted to a cover of brush and hardwoods prove that past efforts to combat the ecological trend have been too few or too late (fig. 1).

Extensive programs to return these lands to pine are now under way in the coastal plain. The techniques used are far from simple or inexpensive. For the most part, the inferior hardwoods and brush require removal by costly mechanical methods. In many instances, hand planting is necessary. Even when machine planting or direct seeding is possible, the total cost of conversion can only be justified by the establishment of fully stocked plantations of pine. Consequently, only minimum losses to plant competitors, insects or diseases can be tolerated—a Herculean objective, as many forest managers discover.

Because of all these troubles, there is definite need for low-cost cultural measures which will effectively arrest the trend toward hardwoods in the remaining natural stands of loblolly pine. Basic qualifications for any practical measure are: (1) In immature pine stands, the treatment must kill or weaken undesirable hardwoods and shrubs that would later prevent the establishment of pine seedlings and (2) in mature stands, it must remove heavy litter and any residual plant competitors which may interfere with natural reseeding at the time of timber harvest. Prescribed burning is a low-cost cultural measure which meets these requirements at least in the loblolly pine stands of the Carolina coastal plain (fig. 2). This is borne out by investigations carried on at the Charleston, S. C., Research Center since 1946. Results from comprehensive plot studies show that most broad-leaved species in the understory can be controlled or even eradicated by a few fires, without damage to the pine overwood or to the site itself.

Figure 1. --Although loblolly pine seed trees are present, this site was captured by the advance understory at time of harvest cutting. Understory control before cutting assures pine regeneration on sites like these.

Figure 2. --The cost of prescribed burning is low because it can be done with small crews using simple hand tools and low-cost plowed fire lines.

CONTROL BY FIRE

The use of prescribed fire in the silviculture of loblolly pine is not a new notion. H. H. Chapman strongly supported its use (1942) in loblolly pine stands west of the Mississippi River (*4, 5*). Chapman's work was given early recognition (1949) by L. E. Chaiken in relation to the problem of controlling inferior species in loblolly pine stands of the Carolina coastal plain (*1*).

More than a decade of study on the Santee and Westvaco Experimental Forests[1] has determined that, for understory hardwood control, the best results with prescribed fire are obtained in loblolly pine stands where the ground is covered with a continuous mantle of fuel consisting mainly of fallen pine needles and similar fine material. Furthermore, most of the understory stems should be under 2 inches d.b.h., as many larger stems can escape control by fire. Depending on the degree of control desired, a forest manager can use either winter or summer fires. The winter fires won't kill many of the hardwoods, as most resprout regardless of the frequency of burning. However, from a practical standpoint, winter burns can be spaced about 5 to 10 years apart and the understory thus held to small-size stems subject to further control by fire as needed. The best use of a short series of summer fires is for hardwood eradication and seedbed preparation about the time of the harvest cut.

Experienced personnel can prescribe burn small tracts for less than fifty cents per acre. Consequently, a full schedule of winter and summer fires for hardwood control and seedbed preparation would cost about $5.00 per acre over a sawtimber rotation.

Furthermore, there is little to fear regarding possible damage from well planned and executed prescribed fires in coastal plain loblolly pine stands above sapling size. Damage to the pine stand from an intense summer burn is avoided by fuel reduction obtained from prior winter burns. Intensive plot studies show that prescribed burning causes no significant difference in the radial growth of dominant pine in any season, even after 10 consecutive annual fires. As a matter of fact, the evidence is that radial growth is more sensitive to amount of soil moisture available in the early growing season than it is to any program of prescribed burning.

Of great significance is the fact that prescribed burning does no damage to the typical sandy loams of the coastal plain loblolly pine sites. No ill effects to the soil were measured over 10 years of plot studies which included annual winter and summer fires (10 each) and periodic[2] winter and summer fires (2 each), as compared to no fires during the period.

It becomes apparent then, that the benefits from prescribed burning overwhelmingly favor its use in the silviculture of coastal plain loblolly pine. The reasons are more fully discussed in the following pages.

THE STUDY AREAS

FIRE TREATMENTS

Formal prescribed burning tests were carried out on ¼-acre plots located in two typical South Carolina coastal plain loblolly pine stands. The treatments compared summer and winter fires, including annual versus periodic applications (table 1). One series of plots was established in 1946 followed by a partial series in 1951. Three replications of all plots were on the Santee Experimental Forest and two replications at the nearby Westvaco Forest, making a total of 35 plots.

STAND DESCRIPTION

The Pine Overstory

Both experimental forest installations were in previously unmanaged but well stocked, even-aged loblolly pine stands containing uniformly distributed, heavy understories (fig. 3). In each case the loblolly pine overstories contained some scattered shortleaf (*Pinus echinata* Mill.), an occasional longleaf pine (*Pinus palustris* Mill.), and miscellaneous hardwoods. The Santee plots, installed in a 40-year-old stand, had 3 subsequent improvement cuts, one at the beginning of the study followed by 2 cuts at 5-year intervals. The 30-year-old Westvaco stand was cut twice, at the beginning and 10 years later. All were commercial operations, thinning mainly from below with very little disturbance of the overwood or understory.

[1] The Santee Experimental Forest, operated by the Southeastern Forest Experiment Station, is on the Francis Marion National Forest in Berkeley County, S. C. The Westvaco Forest is owned by the West Virginia Pulp and Paper Company and lies in Georgetown County, S. C., about 20 miles northeast of the Santee.

[2] "Periodic fire" is used in this report to designate prescribed fires at irregular intervals of three or more years.

Table 1.--Schedule of prescribed burning treatments, Santee and Westvaco Experimental Forests, 1946-1957

Fire treatments	1947 1/	'48	'49	'50	'51	'52	'53	'54	'55	'56	'57
1946 Series											
Annual Winter	X	X	X	X	X	X	X	X	X	X	X
Annual Summer	X	X	X	X	X	X	X	X	X	X	X
Periodic Winter	X	--	--	--	--	X	--	--	--	--	--
Periodic Summer	X	--	--	--	--	--	--	X	--	--	--
No fire	--	--	--	-	--	--	--	--	--	--	--
1951 Series											
Annual Summer	--	--	--	--	X	X	X	X	X	X	X
Biennial Summer	--	--	--	--	X	--	X	--	X	--	X

1/ Dates and X's designate first growing season following prescribed fire.

Figure 3.--Stand conditions at the Santee Experimental Forest location in 1947 before any prescribed burns. Small understory stems in this picture are mainly sweetgum and southern bayberry.

The Understory

Many hardwood species occupied the understories. The major ones included sweetgum, blackgum, and mixed oaks such as post oak (*Quercus stellata* Wangenh.), blackjack oak (*Q. marilandica* Muenchh.), willow oak (*Q. phellos* L.), and southern red oak (*Q. falcata* Michx.). Among the less important trees numerically were flowering dogwood (*Cornus florida* L.), red maple, American holly (*Ilex opaca* Ait.), and miscellaneous hickories. Approximate stocking by tree species-group was 60 percent gum, 30 percent oak, and 10 percent other species.

Southern bayberry, pepperbush (*Clethra tomentosa* Lam.), and gallberry (*Ilex glabra* L., A. Gray) comprised most of the shrub understory. About 60 percent of the understory stems were trees, the remainder shrubs.

A stem tally from two circular 1/100-acre subplots on each check plot at the Santee location showed that most of the understory stems were less than 1 inch d.b.h. at the beginning of the study (table 2). Even so, over 400 stems per acre were 1 inch in diameter or larger, indicating that the prescribed burning treatments were being applied none too soon.

Much of the understory at each location dated from the last wildfire, which had occurred about 15 years before the study began.

Table 2.--Estimated number of understory stems per acre before treatment

Size	Hardwoods	Shrubs	All
	- - Number of stems - -		
Under 4½ ft. tall	4,170	3,970	8,140
D.b.h. class			
0 in.	1,570	320	1,890
1 in.	180	50	230
2 in.	30	--	30
3 in.	50	--	50
4 in.	50	--	50
5 in.	30	--	30
5+ in.	20	--	20
Total	6,100	4,340	10,440

SOIL DESCRIPTION

The experimental forests lie within the flatwoods portion of the coastal plain at elevations of about 40 feet above sea level.

The burning experiment on both forests was installed on Coxville very fine sandy loam, which is a poorly drained soil with very slow surface runoff and medium to very slow permeability. Although of limited importance to agriculture, it produces very good stands of loblolly pine. The soil, which occurs on level to slightly undulating terrain, is also found over much of the lower coastal plain of South Carolina, both in the higher and lower flatwoods areas. Characteristically, the soil has a surface of 2 or 3 inches of dark grey, very friable, fine sandy loam which blends into a light grey, very friable, fine sandy loam with some yellowish mottles appearing at a depth of about one foot. From 12 to 20 inches there is a mottled light grey, yellow to reddish-yellow, slightly plastic, fine sandy clay loam which overlies a clay containing mottlings of red, yellow, and grey.

The whole profile is very acid, low in nutrients, and the organic matter content decreases sharply below the surface 3 or 4 inches.

EFFECTS OF PRESCRIBED FIRE

In addition to determining degree of hardwood control obtained from the various fire treatments, the study appraises their effects on overstory growth and certain soil characteristics. The most complete evaluation involves 10 years of treatment on the series of plots established in 1946. The later series (1951) covers only a 7-year period and provides supplemental information relative to understory control only.

ON CONTROL OF THE UNDERSTORY

Since much of the understory in recently burned loblolly pine stands consists of sprout clumps, a stem count may not be a good basis for an area-wise evaluation of prescribed fire as a control measure. An estimate of the area occupied by the crowns of the understory hardwoods and shrubs is better because it directly reflects the amount

of shaded ground, or the seedbed area currently unavailable for the establishment of pine seedlings. Such an evaluation of the understory was made during September 1956 by means of a 2-percent line transect survey. To do this, we divided the 1946 series of treatment plots into four quadrats, and randomly located parallel lines run across each quadrat. The vertically projected distances of the crowns of stems over 1 inch d.b.h. (high shade) and under 1 inch d.b.h. (low shade) and length of line classed as open (bareground, grass, herbs, etc.) were measured separately. The pine canopy was excluded since, at the most, only scattered seed trees would be left after a regeneration cutting.

The 10th year examination of the 1946 series of plots showed, by comparison with the unburned (check) plots, that all of the tested fire treatments had some effect on the understory shade (table 3). However, the indicated differences in understory shade between the check, annual winter, periodic winter, and periodic summer plots largely reflect the number of growing seasons (age of rough) since last fire. Few, if any hardwood rootstocks were killed by the aforementioned fire treatments. Given the same interval of recovery from fire, the understory development should be more or less similar on these plots. In contrast, the succession of annual summer fires practically eradicated the understory. The check plots had more high shade than any of the others, mainly due to understory growth uninterrupted by fire.

Each of the two fires in the periodic winter series resulted in some reduction of high shade, but the main effect was to kill back most of the low vegetation. Early in the following growing season all rootstocks would resprout, and in a short period of years the understory regained its competitive position. Thus, in the five growing seasons since the second winter fire, low shade competition matched that on the check plots. Obviously, another fire was needed to set back the understory development here.

The two periodic summer fires had a somewhat greater impact on the understory. One reason is that summer fires effectively girdled more of the larger hardwoods than winter fires did, thereby further reducing the amount of high shade. Moreover, there was also a greater reduction in area covered by low shade. Part of this reduction was probably due to the fact that each summer fire killed both stem and roots of some hardwoods and shrubs, bringing about an actual reduction in the subsequent sprout population. However, as shown in table 3, much of the difference can be attributed to a shorter interval since the last fire, which was only about two-and-a-half growing seasons compared to five on the aforementioned winter plots. On roughs of similar age, the indicated difference in low shade competition would not be so great.

The age of the rough had an even more important bearing on the amount of low shade measured on the plots burned annually in the winter, as there was no apparent reduction of rootstocks even after 10 fires. Actually, a cessation of burning would probably lead to a buildup of understory competition equal to that of the check plot, given time. The comeback might be slower than on plots burned less frequently, as there appeared to be a very gradual decline in sprouting vigor over the 10-year period. Also noteworthy was the apparent small reduction in high shade competition on these plots. Any kill of the larger stems probably resulted from the initial fire which, because of the

Table 3.--Effect of prescribed fire in reducing understory shade in immature loblolly pine stands during a 10-year period

Treatment	Growing seasons since last fire	Fires	High shade 1/	Low shade 2/	High or low shade or both 3/
	Years	Number	- - Percent of total area shaded - -		
Check (no fire)	25.0	0	45	69	82
Periodic winter fire	5.0	2	28	71	79
Periodic summer fire	2.5	2	20	57	65
Annual winter fire	1.0	10	33	39	56
Annual summer fire	0.5	10	11	2	12

1/ Shade cast by understory hardwood or shrub stems over 1 inch d.b.h.
2/ Shade cast by understory hardwood or shrub stems under 1 inch d.b.h.
3/ These values are not the sum of high and low shade, as they overlap.

heavy fuel accumulation present, was by far the hottest of the series. Subsequent fire intensity has been low because of a light volume of fuel, but sufficient to kill back the annual growth of sprouts.

The most drastic effect came from the annual summer fires, which almost eliminated the understory (fig. 4). This was true eradication, as the majority of rootstocks, large and small, were killed. Unfortunately, annual measurements of fire effects were not made on the 1946 series of annual summer treatment plots. After about the fourth annual summer fire, however, it was obvious that there already had been a substantial reduction of the understory. Most understory survivors had extremely low vigor and would offer a minimum of competition if pine regeneration had been scheduled at that time.

A second series of plots installed in 1951 gave us a more complete evaluation of the effects of the repeated summer fires. This series compared biennial fires with annual fires, on the assumption that weather conditions might prevent burning in some years. In 1946 this had happened on the Westvaco plots when the burning was postponed due to excessive rainfall. Nevertheless, since the initiation of the 1951 series, all summer treatments have been on schedule at both Westvaco and Santee. A chief difference between years is the length of time available for burning during a growing season; by following a policy of burning at the first opportunity after June 1, advantage was taken of even the shortest period available.

The effect of repeated fires on the understory in the 1951 plot series was evaluated by major species on randomly located 1/100-acre subplots. Where possible, five single understory stems each of southern bayberry, sweetgum, blackgum, and miscellaneous oaks were identified by means of wire pins. One year after each burn the plots were checked to determine survivors. Early results have already been reported (*8*). These and later measurements showed that most southern bayberry and sweetgum succumbed rapidly (fig. 5). In contrast, it took about five successive annual fires to eradicate as much as half of the blackgum and oak. Regardless of species, most survivors showed some signs of reduced sprouting vigor after the first several fires. Thus, it appears that satisfactory levels of understory control, at least adequate for good pine regeneration, can be obtained with just a few successive annual summer fires. Depending on species composition of the understory, 2 to 4 fires should be enough.

The mortality rate from biennial fires was about the same as in the annual series, at least for the first 3 fires. As a matter of fact, missing a year in a sequence of annual fires would have little or no effect on the level of control obtained with a given number of treatments. Consequently, in any large-scale program of summer prescribed burning, delays of a year due to bad weather would be unimportant on areas undergoing treatment. Furthermore, in areas of sparse fuel, prescribed burning could be purposely delayed a year to obtain a better buildup of fuel.

The reasons are not clear for the small amount of mortality following the fourth biennial fire. Only time will determine whether this is a definite trend.

ON GROWTH OF THE OVERSTORY

In an earlier evaluation, McClay concluded that a gradual reduction in understory competition brought about by summer fires, or the annual setback of the understory from winter fires, did not result in any measurable growth benefits to the pine overstory during the first 5 years of the study (*13*). This was also true for the first 10 years. As before, the growth measurements were based on increment borings from every pine tree on the plots; from these, mean yearly radial growth was determined by all treatments and crown classes for the 10-year periods before and after installation of the study. In sum, the data show no statistically significant increase or decrease in growth of the dominant trees attributable to prescribed burning.

The trend of annual growth was downward, which is considered normal for stands of the ages and densities sampled in this study. Much of the yearly variation in growth seems to be closely related to the amount of rainfall during the first 6 months of each year, growth dropping when rainfall during this period was short and taking a sharp turn upward when abundant. An exception is in 1948, which showed a downward trend in growth in the face of a wet first half. A cold early growing season may have been responsible. Furthermore, the possible effect of hot initial burns on growth should not be overlooked, in that the heavy 15-year accumulation of fuel causes these fires to be more intense than any of the later ones, with possible adverse but short lived effects on growth.

Over the years, mortality due to prescribed burning has been negligible. None ever resulted from the winter fires, either annual or periodic. Five trees were killed at the Santee as a consequence of the initial summer burning. Six trees died at Westvaco following the third annual summer fire. In both cases, poor technique is blamed;

Figure 4. --Annual summer fires can eradicate the understory. Above, before fire (one improvement cut). Below, 10 years later (stumps from three improvement cuts).

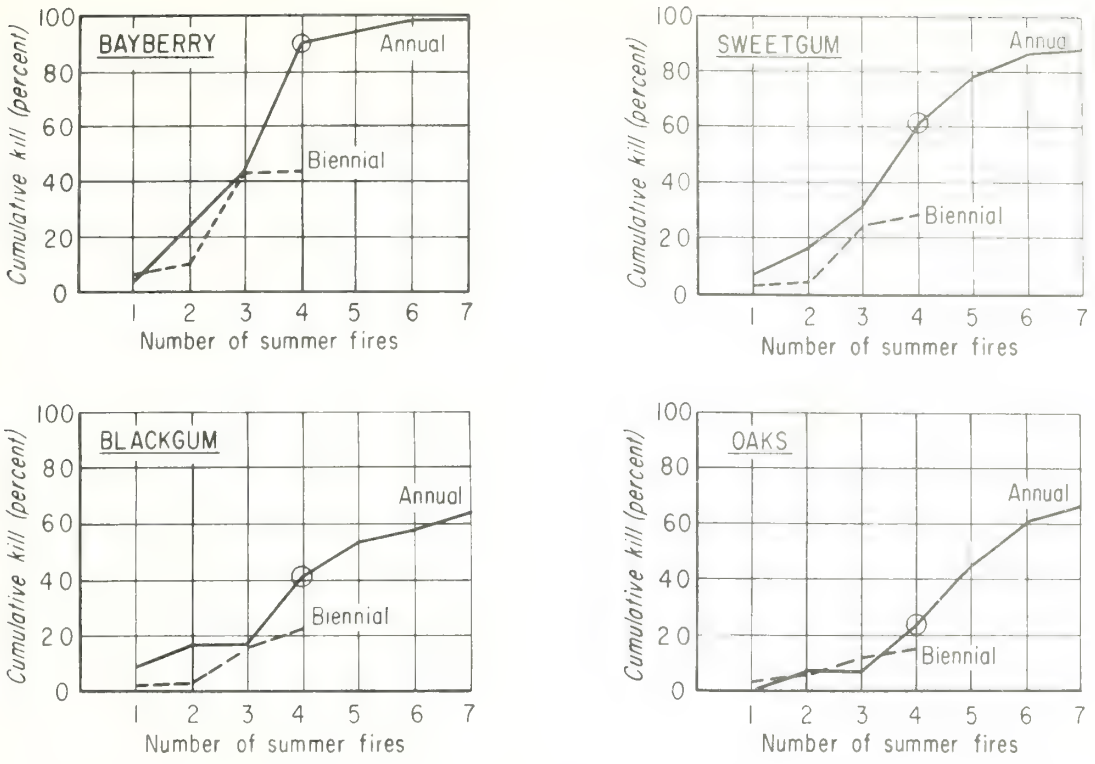

Figure 5. --Cumulative kill of certain understory species in even-aged 40- to 50-year old stands of loblolly pine prescribed burned with a series of summer fires.

the stringing of fire around all sides of the plots caused severe crown scorch from the funneling of heat up into crowns. Some of the weakened trees later succumbed to bark beetles. On most other occasions, summer burning was with backfires. Occasionally a head or flank fire was used to expedite burning light roughs or flat fuels. In each case, the heat was sufficiently dispersed by the wind to avoid any crown damage.

No butt damage to sound trees followed any of the fire treatments. Early in the experiment some trees, catfaced from earlier wildfires or cankered by fusiform rust (*Cronartium fusiforme*), caught fire. These trees were a mop-up problem. However, very few were lost and most were subsequently salvaged in one of the improvement cuts.

ON SOIL

The various soils analyses — organic matter, physical, and chemical — indicate no evidence of serious damage to soil as a consequence of any of the prescribed burning treatments; in fact over a 10-year period of treatment there is a definite increase in organic matter content of the surface 2 inches of forest soil as a consequence of annual burning (see tabulation).

Treatment	*Organic matter based on ovendry weight* (Percent)
Annual summer fire	10.80
Annual winter fire	10.76
Periodic summer fire	9.49
Periodic winter fire	7.04
No fire (check)	7.79

The incorporated organic matter in the burned plots was very black and gave the appearance of being like fine bits of charcoal. Apparently it was not, as the analytical technique (wet combustion method) excludes 90 to 95 percent of the charcoal. Much of the surface litter is not converted to ash, and the material which appears to be charcoal is actually charred matter. This fine residual left after a fire can enter the mineral soil by gravity or by water if it is not washed away, which is unlikely in the flat coastal plain. This is in contrast to the unburned forest floor, where litter slowly changes to humus and while a portion of it is being incorporated into the mineral soil, much of the material volatilizes as carbon dioxide and water vapor.

Analyses of the upper 2 inches of surface soil revealed that organic matter significantly increased with all fire treatments except periodic

winter fires—in which case organic matter remained at about the same level as on the unburned areas. Furthermore, the soil nutrients, nitrogen, phosphorus, potash, calcium, and magnesium, were closely correlated with the organic matter content in the surface soil. Finally, type and frequency of fire treatments tested resulted in no detrimental effect on the physical properties of bulk density, porosity, or percolation rate, all of which are more or less related to the organic matter in the soil.[3]

It should be pointed out that organic matter in the soil was already of sufficient quantity so that the measured increases are not important biologically. There is now confidence that on the level sandy soils of the Carolina coastal plain no site deterioration results from a program of prescribed burning in the loblolly pine type.

A word of caution in this regard may be in order. The results of this study cannot be applied to sloping terrain or to sites on which the soil at the surface is not sandy. On the sites studied there is practically no horizontal movement of surface water. But on sloping land, water moving over the surface would tend to carry ash and charred material from the site and at the same time material in suspension would settle out and plug the surface soil pores. Sealing of the surface by moving water would be more rapid on non-sandy soils. And of course, in the Piedmont, mountains, and sandhills, where organic matter is often but 1 or 2 percent, the reaction of the site to fire could be considerably different.

PRACTICAL SIGNIFICANCE OF THE STUDY

WHERE RESULTS APPLY

As a consequence of this study, considerable information has accumulated on the use of fire in loblolly pine silviculture. The present findings apply mainly to relatively pure pine stands consisting of pole-size or larger trees. In these stands the fuel type is fairly uniform and comprised largely of pine needles and similar fine material (fig. 6). Scattered patches of flat fuels, mostly hardwood leaves, may be present but not in amounts sufficient to reduce the general effectiveness of a prescribed burn (fig. 7). In any event, primary uses of fire would be for understory control or seedbed preparation. This requires that for best results the majority of understory stems be under 2 inches d.b.h.

Although each fire results in some fuel reduction, this objective is more important in sapling pine stands, an age group excluded from our study. Consequently, additional investigation is needed to adequately appraise the value of prescribed burning for hazard reduction. Furthermore, our study does not cover the use of fire on former pine lands now in hardwoods or brush. A prevalence of flat and sparse fuels on these sites may require burning conditions bordering on the explosive for effective treatment, and thus mechanical or chemical treatments are likely to be more practical than fire for type conversion purposes.

Some of the fire treatments included in the present study are backed up by tests on larger areas of coastal plain loblolly pine in and out of the Santee Experimental Forest. These pilot burns ranged up to about 50 acres. Major treatments tested were periodic winter fires and annual summer fires, separately or in combination, as these gave early promise of having practical application. The possibility of serious damage precluded the use of periodic summer burns on large tracts. Furthermore, the annual winter fire treatment was not tried beyond the study plots, as no advantage over periodic winter burning was apparent. The required conditions for safe but effective burns on large areas were generally much the same as on the ¼-acre plots. Therefore, the following information should serve as a useful guide to the treatment of immature loblolly pine stands for hardwood control and/or seedbed preparation on areas as large as several hundred acres.

PRESCRIBED BURNING TECHNIQUES

Fires were scheduled on the study plots as soon as weather permitted after December 1 (winter) and June 1 (summer). Thus, most of the experimental winter burning was done in December or January, although delayed as late as March 15 one year. The bulk of the summer burning was completed in June, but not until July 22 on one occasion. There appears to be no valid reason why a winter burning season could not extend over about a 4-month period in any large scale burning program, commencing with the first killing frost in November and ending at the beginning of the growing season in March. Likewise, the summer season could extend from early May on into September, also about 4 months. This exten-

[3] A comprehensive discussion of soils on these same study plots is given in the paper, "Some Effects of Prescribed Burning on Coastal Plain Forest Soil." Publication is pending.

Figure 6. --Above, needles draped on understory stems, a common condition in areas infrequently burned, add to fire intensity. Below, accumulation on ground, in this case about 20 years since last wildfire. Note section cleared to mineral soil to illustrate depth of fuel.

Figure 7. --Flat fuels, mostly hardwood leaves, are less flammable than pine fuels and often do not burn when conditions are suitable for firing pine fuels.

sion was substantiated by the pilot burns, some of which were made in late summer.

In spite of best laid plans, fire treatments could not always be carried out as scheduled. Periods of heavy or frequent rains caused most delays. For example, flooding and excessive fuel moisture brought about a year's postponement in establishing the summer burn plots at Westvaco. For similar reasons, there was one less fire than scheduled in the annual summer series at that location. In addition, it was impossible to burn one of the annual winter fire plots in 1948 or 1949, and two were bypassed in 1958. In contrast, all of the Santee plots were burned as planned.

In the winter the average waiting period after a rain of ½ inch or more was 18 days before burning conditions were right. In contrast, the average drying out period in the summer amounted to only 10 days. Conditions were seldom right in any season in less than 3 days after a soaking rain. Small areas of flat fuels composed mostly of hardwood leaves dried more slowly and were generally less flammable than the more extensive area of pine litter. Complete fuel consumption by a fire required waiting until both the litter and soil surface dried out. Generally, a dry upper layer of litter sufficed to carry an adequate burn in pine fuels (fig. 8). Almost complete drying was needed in the flat hardwood fuels for effective results.

Favorable weather elements for burning included air temperatures of 60°F. or above in winter and 90°F. or above in summer, relative humidities under 50 percent in both seasons, and winds steady as to direction, but generally within a range of 1 to 7 miles per hour at about breast height in the stand (table 4). Such winds maintained sufficient draft to ignite fresh fuel, carried water vapor and heat at an oblique angle through the pine crowns (minimizing danger of crown scorch), and gave assurance that a fire moved in a direction and rate as planned. Fuel moisture, determined from basswood sticks, never exceeded 10 percent at the time of burning, and generally was around 5 to 8 percent.

Unfortunately, most of the foregoing factors were measured only on days scheduled for prescribed burning. This makes it difficult to estimate, as a possible guide to planning larger burning programs, how many additional days or periods might have been suitable during the 10 years. There is a clue, however, in the continuous record of relative humidity recorded on the hygrothermo-

Figure 8. --Upper third of picture shows forest floor immediately after the first winter burn, ember still smoldering. Middle third shows unburned litter. In lower third, mineral soil has been exposed to show depth of litter. Note the thick cover that remains after the burn, protecting mineral soil and fine roots.

Table 4. --Prevailing weather conditions for prescribed burning of plots at Santee Experimental Forest

Date	Burning began	Maximum air temperature	Minimum relative humidity	Wind		Fuel moisture	Days since ½ inch or more of rain
				Direction	Speed		
	Hour	Degrees F.	Percent		M. p. h.	Percent	Number
ANNUAL WINTER FIRES							
Dec. 6, 1946	1:00 p. m.	60	20	Variable N	1-3	10	8
Feb. 19, 1948	3:00 p. m.	68	44	Variable N	1-3	10	7
Jan. 17, 1949	12:30 p. m.	75	50	SW	1-3	10	18
Dec. 7, 1949	1:00 p. m.	61	32	SW	1-3	8	30
Jan. 29, 1951	1:00 p. m.	71	48	SW	1-3	7	29
Dec. 3, 1951	1:00 p. m.	72	42	Variable SE	1-4	5½	30
Dec. 12, 1952	2:00 p. m.	60	30	Variable NW	1-3	5½	31
Jan. 8, 1954	1:30 p. m.	60	40	SE	1-3	7	10
Jan. 5, 1955	1:30 p. m.	72	46	Variable SW	1-3	9	3
Jan. 3, 1956	1:00 p. m.	70	40	Variable SW	1-6	8	30
Dec. 28, 1956	1:00 p. m.	69	30	SW	3-6	5	4
Average	1:10 p. m.	67	38	--	1-3	8	18
ANNUAL SUMMER FIRES							
June 19, 1947	1:00 p. m.	94	24	Variable	1-3	--	5
June 17, 1948	1:00 p. m.	84	46	E	1-3	--	9
July 11, 1949	12:45 p. m.	90	47	E	1-3	--	15
June 14, 1950	2:00 p. m.	87	46	SW	1-3	5½	6
June 28, 1951	1:00 p. m.	99	43	Variable	1-3	--	5
June 10, 1952	1:00 p. m.	95	45	W	1-3	5	29
July 1, 1953	12:30 p. m.	96	39	SW	1-3	4½	2
June 15, 1954	1:45 p. m.	90	38	NE	4-7	3	3
June 7, 1955	12:30 p. m.	92	33	SW	4-7	3½	14
June 18, 1956	2:45 p. m.	95	34	SE	3-4	9	12
July 9, 1957	12:30 p. m.	97	38	Variable N	1-3	4½	12
Average	1:02 p. m.	93	39	--	1-3	5	11

graph maintained at the Santee Experimental Forest Headquarters weather station. Experience has shown that on days with minimum relative humidity under 50 percent, pine fuels were sufficiently flammable to carry a prescribed fire. On this basis, an average year contained a total of 37 possible burning periods about equally divided between the winter and summer seasons, as shown in table 5. (Table 5 is based on 10 years of measurement.) For planning purposes 37 periods should be considered about maximum, especially in the absence of supplemental information on the number of days with steady but light winds. Consideration must also be given to the difficulty of mobilizing an organization within burning periods as short as 1 or 2 days, which comprise over 40 percent of the total. Even so, we find that there isn't much difference between the winter and summer season, and thus ample opportunities for prescribed burning should develop during a normal year in either season.

Frequently, a final decision to prescribe burn needed to be checked by a test fire in a typical fuel condition within a treatment area. A test fire that smoldered and did not spread uniformly from the center usually caused postponement until later in the day or another day. But if the test fire crept out uniformly and burned well, a prescribed fire followed immediately. Suitable burning conditions generally developed about midday and continued until late afternoon, when rising humidity prevented a further spread of fire. For safety reasons — to minimize crown scorch or the escape of fire from plowed lines — burning conditions resulting in a flame height of less than 4 feet were preferred, especially where fuel accumulations were heavy. On the other hand, in an annual and biennial burning treatment series, light fires—resulting from the thin fuels—were the rule and sufficed to control the 1- or 2-year-old sprouts (fig. 9).

Most areas were burned against the wind, especially at the initial treatment. However, the rate of spread for the backfires seldom exceeded 2 chains per hour. On 1- or 2-year-old roughs, or light fuels, flanking fires and strip head fires helped to expedite burning; but it was bad practice to surround an area with fire. On the two occasions when fires were strung around entire plot perimeters without regard to wind direction, resultant damage to the overstory plainly indicated this was an undesirable technique for most areas.

By preparing firelines only a short time ahead, we avoided accumulations of leaves and needles and additional maintenance of the lines. On annual and biennial burns the original plowed lines required only hand raking. In contrast, a periodic series of fires, taking place at intervals of 3 years or more, always needed replowed fire

Table 5.--Average number of periods one or more days long having a minimum relative humidity under 50 percent, by months within burning seasons

Number of days in period	Summer months					Winter months					Grand total
	May	June	July	Aug.	Total	Nov.	Dec.	Jan.	Feb.	Total	
	Average number of periods										
1 or 2	2	2	2	2	8	2	3	2	1	8	16
3 to 5	2	2	1	1	6	2	2	2	1	7	13
Over 5	1	1	1	1	4	1	1	1	1	4	8
All periods	5	5	4	4	18	5	6	5	3	19	37

Figure 9. --Annual accumulation of fuel sufficed to carry a light fire on the annual summer treatment plots.

lines. A 2- or 3-man crew did most of the burning on the experimental areas. Mop-up work began with prescribed burning in progress. Occasional checks continued until the fires were considered safe, usually not more than one day after.

COST OF BURNING

The pilot burns provide some useful cost data. Fifteen areas burned for a total of 547 acres, ranging in size from 24 to 53 acres each, developed the following cost information:

Item	*Hourly cost*	*Hours per acre*	*Cost per acre*
TD-9 tractor	$9.00	0.02	$0.18
Mathis plow	2.75	.02	.06
Labor	1.00	.22	.22
		Total....	$0.46

The foregoing represent actual on-the-ground costs. Transportation of personnel and equipment to and from the site is not included; neither is any overhead except that engaged in the burning operation. Very small crews were involved. In addition to tractor-plow operator there were seldom more than two or three men engaged in setting the fires or in any ensuing mop-up operation. Although full dependence was placed on the local protective organization for reinforcements in case of the escape of a prescribed fire, the reinforcements were never called out. Patrol action was held to a minimum.

Prescribed burning on small areas such as these is considered more costly than larger units burned by the local National Forest organization. A 40,000-acre program on the Francis Marion National Forest in 1958 resulted in an average expense of 45 cents per acre. This included planning and transportation of labor and equipment in addition to on-the-ground costs.

As pointed out by Klawitter (*6*), prescribed burning can yield some direct monetary benefits and thus help pay its way. This was determined by a comparison of extraction costs from two adjacent 50-acre areas in the same loblolly pine stand. On an area that was relatively brush free after four prescribed burns, the logging costs for an intermediate cutting operation were reduced

by $2.29 per thousand board feet of saw logs and $1.50 per cord of pulpwood, as compared to costs on the unburned and brushy area. This is the equivalent of $3.95 per acre of decreased logging cost in the burned area, based on a cut of 1,300 board feet and 0.6 cords per acre—enough to pay for eight burns instead of the four that were made.

SILVICULTURAL APPLICATION

The decade of testing on small plots and larger pilot areas showed that prescribed fire is an efficient and low-cost tool for perpetuating even-aged stands of loblolly pine on coastal plain sites. In stands above sapling size, adequate understory control or seedbed preparation is obtainable with no serious damage to the pine growing stock or site. Winter or summer fires may be employed as needed to meet the requirements of the forest manager. Conditions and instructions relative to proper seasonal uses of fire were at least tentatively described in earlier reports of our research results (*2, 3, 9, 7, 10, 11*). With some refinements they are discussed below.

Winter Fire

As previously pointed out, little is gained from a series of annual winter fires. Most rootstocks survive, and when the treatment is stopped the understory will regain its competitive position in a few years. A comparable level of control can be obtained by burning only occasionally, thus helping to reduce costs. Frequency of reburning depends, of course, on the rate of understory development after each fire. In this respect, intermediate cuttings often result in more light reaching the understory, thus speeding up its growth. Furthermore, good sites require more frequent treatment than poor ones. Hence the interval between fires may range from several to 10 or more years. Small stems in the understory are effectively girdled by a winter fire. On those up to about 1 inch d.b.h. the kill is high but rapidly diminishes as stem size approaches 2 inches, and is negligible among larger sizes (fig. 10). For best results, this suggests reburning when most stems are still small. A recommended rule of thumb is to reburn when about 25 percent of the largest understory stems are approaching 1 inch d.b.h. Accordingly, on average

Figure 10. --All the understory stems in foreground, including the larger ones, had been killed back by a periodic winter burn. In May following the fire, sprouts were already about 2 feet high.

sites in managed stands this would mean burning at about 5-year intervals, or 8 to 10 fires in an average sawtimber rotation.

The simplest prescribed burning program is one requiring only periodic winter fires. If properly applied, the treatment holds the understory in check during the life of a loblolly pine stand. Then at the time of final harvest the seedbed is prepared with one last winter fire. As a matter of fact, such a program may be described as learning to live with the inferior hardwoods and shrubs of the understory, inasmuch as their rootstocks are not destroyed by the winter burns. A chief danger is that some growing space is invariably captured by the broad-leaved species, the extent depending upon their number, size and aggressiveness. The situation may be worsened by a poor scheduling of the terminal winter fire. If it takes place after the main seedfall, rather full dependence must be placed on the next seed crop for pine regeneration. In the meantime the site may be occupied by sprouts that have a full growing season's advantage over any pine regeneration. An alternative is to burn for seedbed preparation as early in the dormant season as feasible. If done around November 15, about half the seed is still on the trees and would fall on the freshly burned seedbed. By December 15 this proportion shrinks to about 20 percent, and by January 15 to 10 percent or less.

Summer Fire

A more progressive burning program than the foregoing is one that incorporates summer fire into the general schedule of treatments. As a minimum, one would use a summer burn in lieu of the terminal winter burn for seedbed preparation. This assumes that periodic winter fires are used to keep the understory stems small or under control during the immature stages of stand development. Then, a summer burn for regeneration is made sometime during the last growing season, but prior to the final harvest cut. The later in the season burning is done, the less chance there is for sprout development prior to pine seed germination in the following spring. Inasmuch as seedfall begins about October 15, the best timing calls for a prescribed fire during the month immediately preceding this date. For all practical purposes, however, a seedbed-preparation burn any time during the months of June, July, August, or September should do an adequate job—certainly better than any dormant season fire for the same purpose because of lesser sprout growth and no seed loss to fire.

A more intensive regeneration technique involves the use of a succession of annual summer fires, especially in stands with dense underbrush or with limited seed production. These fires can begin several years in advance of harvest to eradicate or weaken much of the understory competition in addition to preparing the seedbed. The sequence of fires can be stopped at the discretion of the forest manager following the establishment of a sufficient number of pine seedlings. Thus, reproduction can be established even before the overwood is harvested (fig. 11). In good seed years or in areas of known good seed production, an alternative is a harvest cut after seedfall following the last summer burn in the series. This utilizes seed in place and eliminates need for seed trees—a pilot test of this suggested technique resulted in 90,000 one-year-old seedlings per acre. In either case the summer fires are preceded by the usual course of periodic winter burns to keep the hardwoods small even though not reduced in number.

A possible maximum use of a succession of summer fires is for practical eradication of the broad-leaved understory about mid-rotation. This calls for a succession of three or more fires, depending on the species composition. For example, an understory with a high percentage of southern bayberry or sweetgum would require less treatment than one with a high proportion of blackgum or mixed oaks. Furthermore, a high degree of initial control would probably be easy to maintain, particularly with the removal of any hardwood seed sources within the pine stand as part of scheduled intermediate cuts. When the understory competition is once reduced to a minimum, an occasional winter fire should suffice to keep down any broad-leaved survivors or volunteer pine, and to reduce fuel. Silvicultural benefits obtained from the practical elimination of the understory often justify this burning program; in addition, one cannot overlook the possible savings in cost of field inventory, tree marking, logging, and timber sale supervision.

In the face of the evidence presented, fire has a definite place in the silviculture of coastal plain loblolly pine. Even so, fire should be considered a tool to be prescribed when and where needed. At the discretion of the forest manager, fire can be used in immature stands of loblolly pine for the control of understory hardwoods and seedbed preparation. The season and frequency of burning depend on the degree of effectiveness desired. In any event, the fires can be prescribed without fear of damage to the stand or site. Provided the burns do not get away and turn into wildfires, benefits far exceed any damage we have been able to measure.

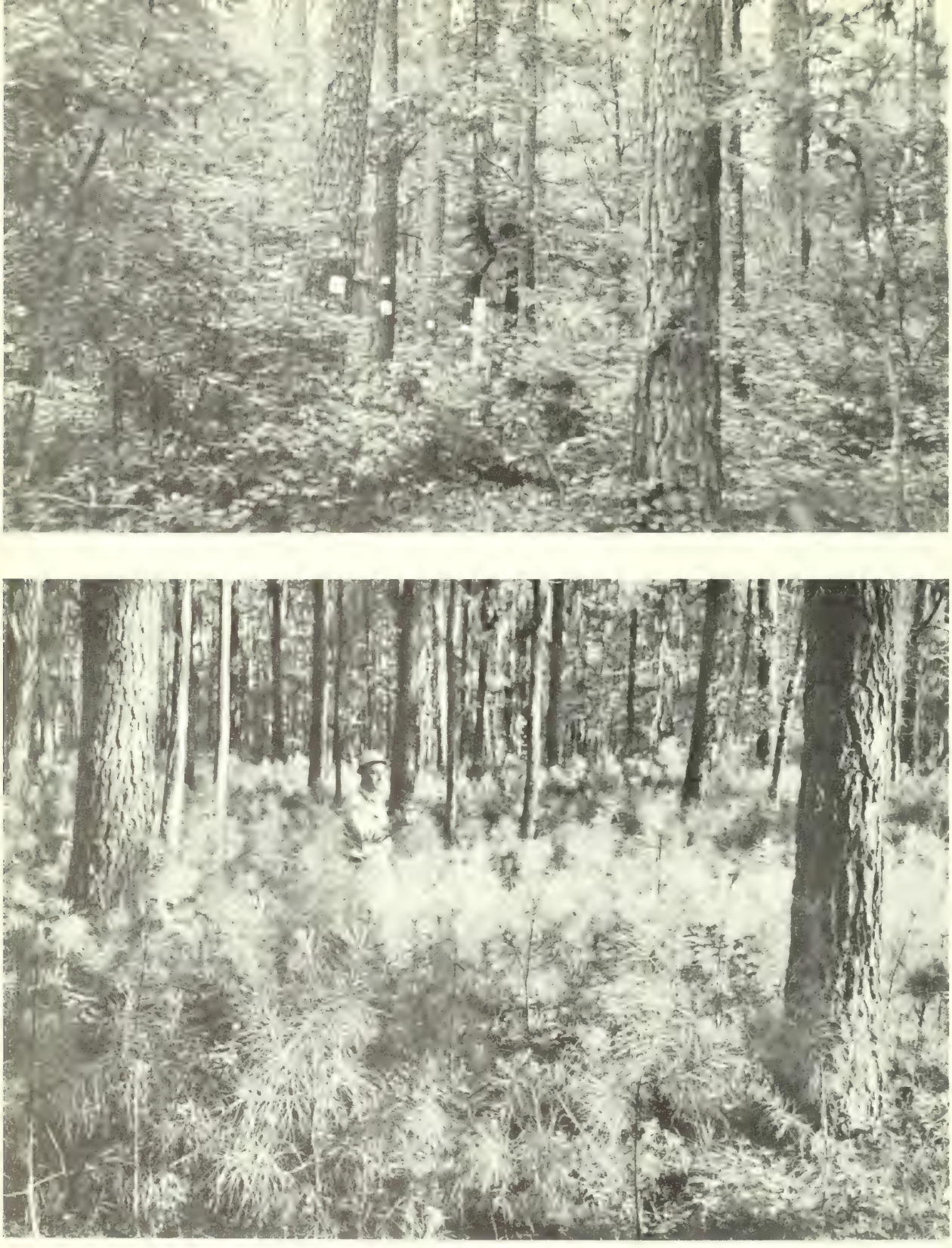

Figure 11. --Above, 50-year-old loblolly pine stand with heavy hardwood understory. Below, one winter and three summer fires later, understory hardwoods replaced by pine even before harvest cutting.

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Agriculture Asheville

Station Paper No. 118 March 1961

Burning Index as a Partial Guide to Air Patrol in the South

by

Ralph M. Nelson

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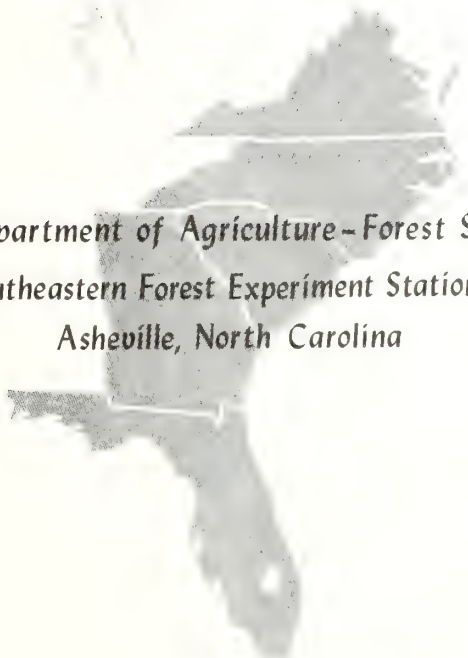

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Burning Index as a Partial Guide to Air Patrol in the South

by

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Division of Forest Fire Research

INTRODUCTION

Aircraft patrols are used for many fire control purposes in the South. A major use is in checking out individual smokes to determine whether or not suppression action by ground units is needed. Air patrols are almost indispensable in scouting and reporting the progress of large fires. During periods when tower lookouts are handicapped by low ground visibility, they are valuable as primary detectors. Also, they have been found effective in various aspects of fire prevention and law enforcement. It seems certain that increasing use will be made of air patrols because of their speed and versatility.

A fire control manager has the problem of deciding how much flying time he can afford and when and where he can buy the most protection for his money. Ordinarily there are few guidelines to help him. He must therefore weigh, as best he can, such factors as fire danger, visibility, activity of fire starters, season of year, values at stake, and the location of blind areas and hot spots, against the amount of flying time at his disposal. However, if accurate records for several years on the effectiveness of air patrol under different conditions were available, probability figures could be developed that would serve as guides to action.

The main purpose of this paper is to illustrate a method for analyzing certain records that should eventually provide useful operational information. The analysis deals only with number of fires, their time of occurrence, and their relation to burning index on the 8-100-0 fire danger meter now used extensively throughout the South. 1/ Other factors that might indicate the need for air patrol, such as visibility, expected increase in risk, and prevention activities, were not considered because information was not available. However, other things being equal, it seems that air patrols should be made at times when the probability of fire occurrence is the greatest. The analysis is based on that assumption.

Records for the analysis were obtained by the Southern Forest Fire Laboratory through a cooperative project with the Georgia Forestry Commission and the Georgia Forest Research Council. Preliminary tabulations were made by personnel stationed at the Laboratory.

1/ For a description of the 8-100-0 meter and its use see: How to Measure Forest Fire Danger in the Southeast by Ralph M. Nelson. U. S. Forest Serv. Southeast. Forest Expt. Sta. Paper 52, 22 pp. 1955.

ANALYSIS PROCEDURE AND RESULTS

For purposes of fire protection, the Georgia Forestry Commission has divided the State into 10 districts, as indicated in figure 1. As of January 1959, 97 fire danger stations were operated by the Commission in counties under protection. To insure the best possible danger records for analysis purposes, 3 to 6 key stations were selected in each of the districts. These 40 key stations were given special attention and were operated yearlong which permitted the derivation of an average burning index for each district for each day of the year.

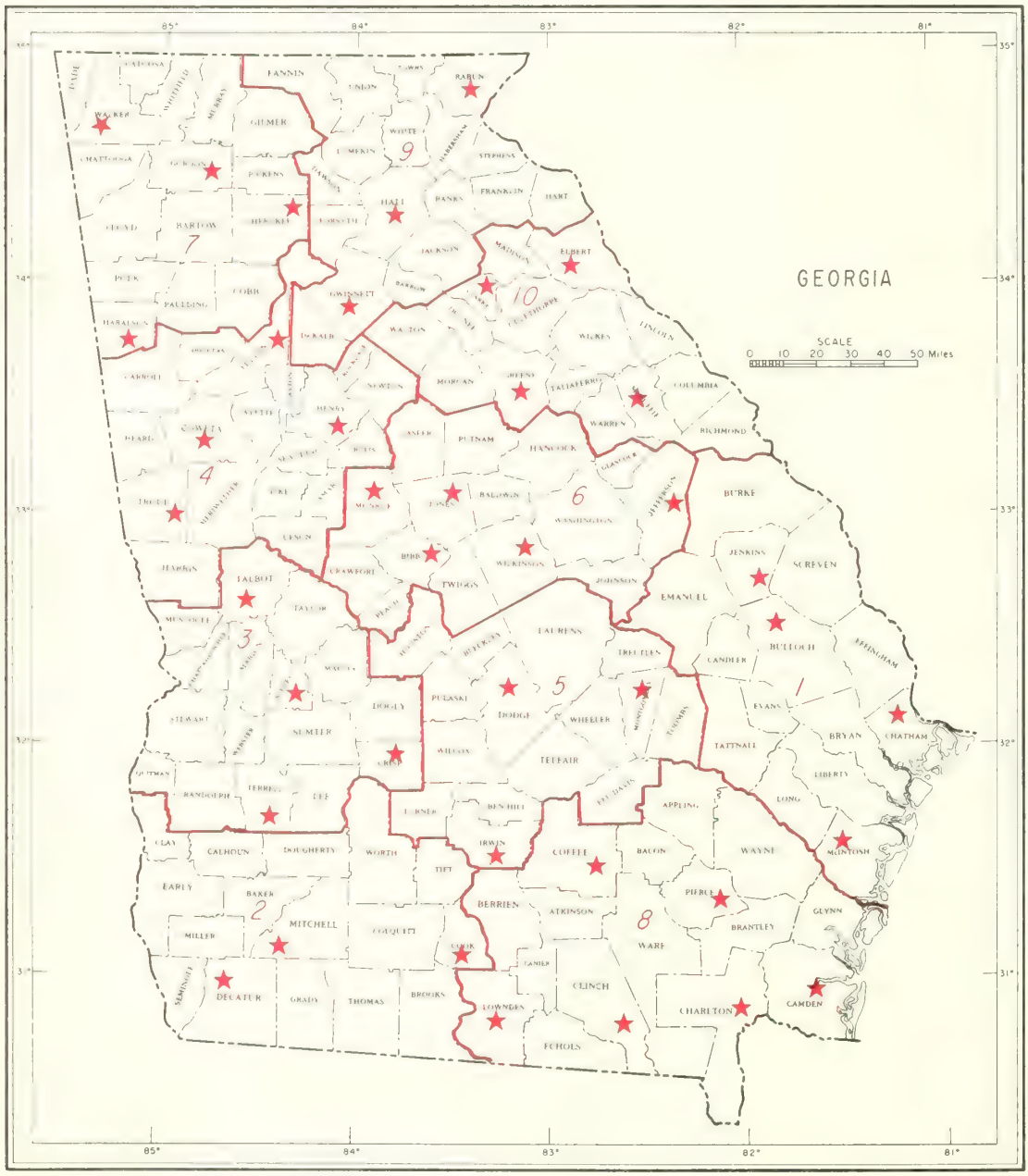

Figure 1. --Location of key fire danger stations and districts.

Fire Occurrence and Fire Danger

The first step in the analysis was to determine the degree of relationship between number of fires and burning index for the State as a whole. This was done by summing the number of days and fires in the 10 districts by each division of the burning index scale (tables 1 and 2). The number of fires was then divided by the number of days for each burning index division to obtain an average rate per day. These rates are plotted in figure 2. As will be seen, the number of fires per day increased as the burning index increased. The points for burning indexes 35, 40, and 45 were not plotted because they were based on so few days as to have little meaning.

Table 1.--Distribution of days by burning index and districts, Georgia, 1959

Burning index	Districts										State total
	1	2	3	4	5	6	7	8	9	10	
	Number										
1	147	147	150	160	155	147	153	138	129	126	1,452
2	62	43	44	54	52	47	68	65	54	68	557
3	26	27	24	36	24	33	30	23	34	25	282
4	15	24	22	21	19	25	18	17	23	32	216
5	20	16	16	17	12	20	14	12	18	22	167
6	13	17	19	10	15	19	10	15	8	12	138
7	15	10	10	12	12	9	9	15	10	8	110
8	10	11	11	9	13	11	6	10	17	12	110
9	8	6	8	7	7	6	8	6	8	4	68
10	4	8	10	6	8	2	8	10	11	9	76
11	7	6	2	5	7	6	3	9	4	4	53
12	6	5	6	3	6	8	4	4	7	10	59
13	8	5	9	5	5	7	11	3	6	2	61
14	6	6	8	1	7	4	4	7	5	3	51
15	--	3	3	--	5	--	2	4	3	4	24
16	3	6	6	3	4	2	2	5	4	7	42
17	2	2	3	3	4	6	--	4	5	1	30
20	7	7	4	6	5	7	6	8	5	5	60
25	5	11	8	5	2	3	5	7	10	6	62
30	1	3	2	2	3	2	2	1	3	3	22
35	--	2	--	--	--	--	1	2	--	1	6
40	--	--	--	--	--	1	--	--	1	1	3
45	--	--	--	--	--	--	1	--	--	--	1
Total	365	365	365	365	365	365	365	365	365	365	3,650

For those who are accustomed to think of fire danger in terms of class day, as indicated on the 8-100-0 meter, rather than units of burning index, the data were rearranged in table 3 by class day and grouped months. January, February, March, April, and December were combined because by far the greater number of fires occurred during these months. Regardless of fire season, there was a pronounced increase in number of fires per class day as measured danger increased. For example, during 1959 in Georgia, there were about 8 times as many fires on each class 4 day as on each class 2 day. Statements have occasionally been heard that more fires occurred on class 2 days than on class 4 days in certain areas. However, when figures were checked, we invariably found that there were also many more class 2 than class 4 days.

Table 2. --Distribution of fires by burning index and districts, Georgia, 1959

Burning index	Districts										State total
	1	2	3	4	5	6	7	8	9	10	
	Number										
1	30	17	16	46	38	27	32	64	8	14	292
2	34	11	23	56	35	27	71	108	17	35	417
3	35	16	12	62	23	40	35	40	16	10	289
4	43	54	26	66	20	47	39	14	24	35	368
5	79	59	15	47	17	26	36	29	24	23	355
6	76	74	26	56	35	44	30	32	13	10	396
7	75	21	27	66	25	28	51	52	17	9	371
8	52	39	23	42	34	28	28	18	24	19	307
9	41	43	23	45	21	9	38	22	12	8	262
10	24	25	35	32	25	3	64	34	31	12	285
11	42	29	6	47	23	12	21	43	4	6	233
12	70	49	15	31	19	29	22	33	34	31	333
13	37	20	20	57	28	25	88	3	18	2	298
14	36	12	20	4	20	18	35	45	27	7	224
15	--	4	8	--	37	--	20	8	35	9	121
16	5	34	27	42	30	9	32	10	5	17	211
17	9	8	14	51	9	15	--	42	39	5	192
20	121	24	9	84	34	30	98	58	24	9	491
25	30	38	67	87	11	12	106	35	114	22	522
30	29	4	15	58	63	15	75	3	52	24	338
35	--	2	--	--	--	--	21	20	--	1	44
40	--	--	--	--	--	--	16	--	--	18	12	46
45	--	--	--	--	--	--	27	--	--	--	27
Total	868	583	427	979	547	460	969	713	556	320	6,422

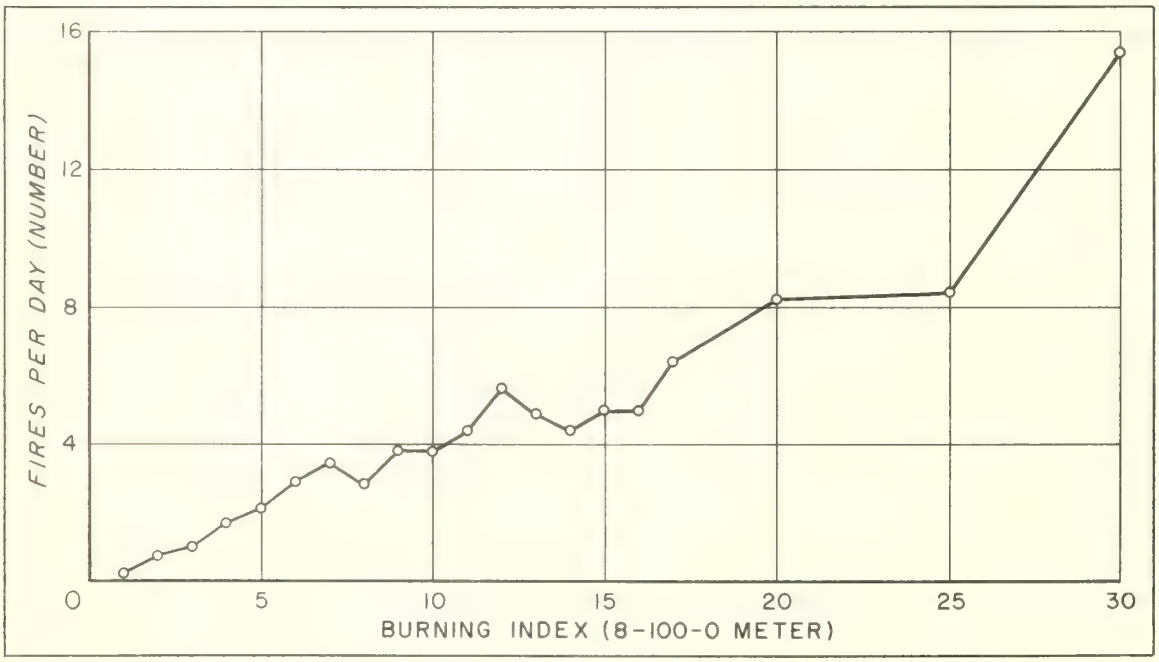

Figure 2. --Number of fires per day by burning index, Georgia, 1959.

Table 3. --Fires per danger class day by periods, Georgia, 1959

Class day (8-100-0 meter)	Burning index range	Jan., Feb., Mar., Apr., Dec.			May through Nov.			All months		
		Fires	Days	Fires per day	Fires	Days	Fires per day	Fires	Days	Fires per day
		Number								
1	1	46	308	0.15	273	1,144	0.24	319	1,452	0.22
2	2 to 5	754	442	1.7	652	780	0.84	1,406	1,222	1.2
3	6 to 17	2,773	615	4.5	460	207	2.2	3,233	822	3.9
4	20 to 45	1,421	145	9.8	43	9	4.8	1,464	154	9.5
Total		4,994	1,510		1,428	2,140		6,422	3,650	

As an incidental point, the positive relation described between number of fires and burning index does not always hold throughout the entire range of burning index. Exceptions are found in areas where there are relatively few fires or when there is abnormal activity by fire starters. Unfortunately, no one yet has been able to explain the vagaries of incendiarists or careless people so that the effect of risk can be taken into account.

The substance of the previous paragraphs is that there were a number of days with certain burning indexes in 1959 during which air patrol would have been more effective than on other days, considering only number of fires that occurred. This will be further explained in following sections.

Time of Fire Origin

A next step in the analysis was to group all fires by reported time of origin. From figure 3 it is clear that for the State as a whole, most fires (71 percent) started between noon and 5 p. m. Because of possible differences among districts, data were regrouped in table 4. Although some differences are apparent, there was fairly close agreement as to percent of fires that originated during specific periods of the day in the 10 districts. Again based solely on the number of fires that occurred, the most effective flying period was between noon and 5 p. m. This is on the assumption that pilot and observer can patrol for 5 hours without undue fatigue.

Relation of Days and Fires to Burning Index

Computations for District 2 (table 5) will illustrate the procedure used in relating number of days and fires to burning index. It was selected for no particular reason except that it held approximately a median position among districts with respect to number of fires in 1959. Only January through April, and December, were used in the calculations because a large proportion of all fires in the State occurred during these months. The number varied by districts, ranging from 64.5 to 88.1 percent of the year's total.

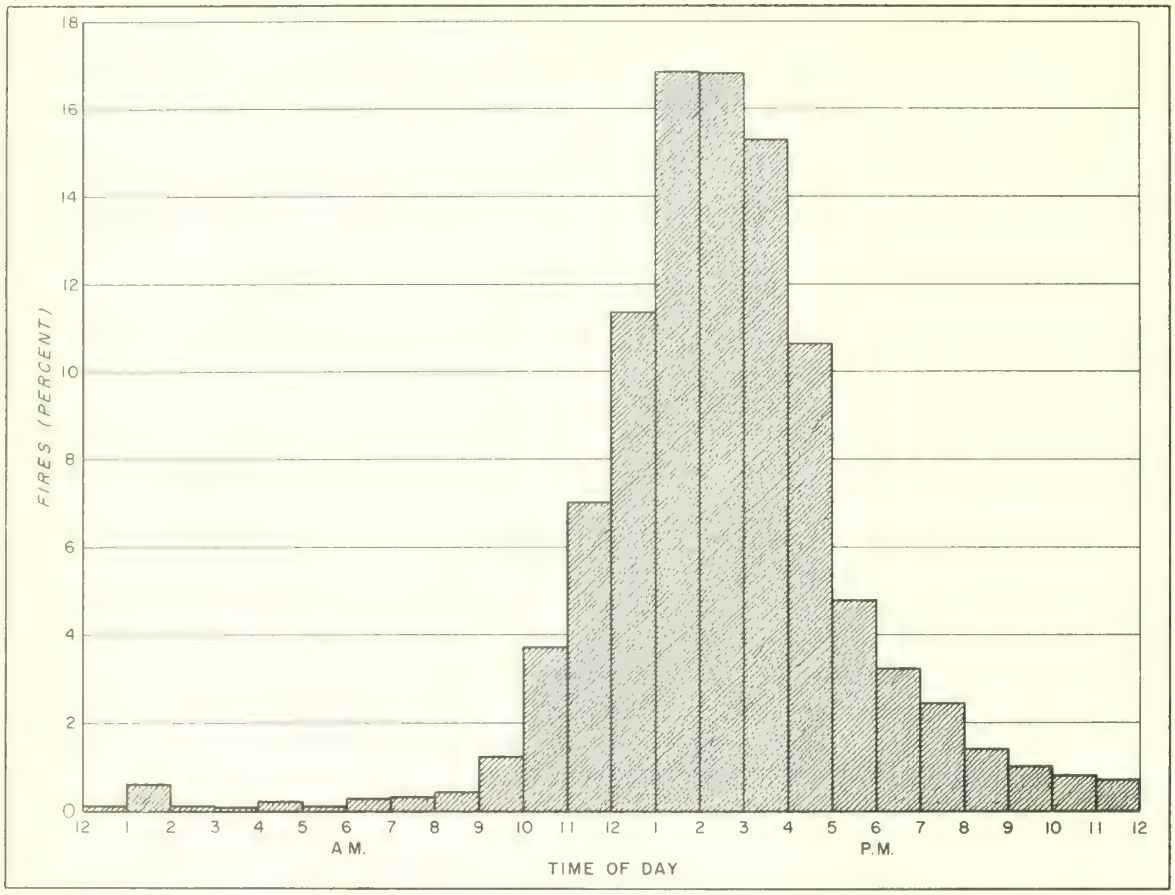

Figure 3. --Fires by hour of origin, Georgia, 1959.

Table 4. --Percent of fires by periods of origin and districts, Georgia, 1959

	Districts										State
	1	2	3	4	5	6	7	8	9	10	
	Percent										
Worst 4 hr. period											
12 noon-4 p.m.	55			63			59		60		60
1 p.m. -5 p.m.		66	62		64	63		65		60	
Worst 5 hr. period											
11 a.m.-4 p.m.	66										
12 noon -5 p.m.		76	72	73	74	75	69	73	70	71	71
Worst 6 hr. period											
11 a.m.-5 p.m.	73	81	79	79	79	82	76	79		81	78
12 noon -6 p.m.									78		

Table 5. --Relation of days and fires to burning index for the period January through April, and December. District 2, Georgia, 1959

Burning index	Days	Days cumulated	Days	Fires	Fires cumulated	Fires	Fires adjusted
	(1) Number	(2) Number	(3) Percent	(4) Number	(5) Number	(6) Percent	(7) Percent
1	26	151	100	8	509	100	76
2	8	125	83	3	501	98	74
3	9	117	77	11	498	98	74
4	12	108	72	47	487	96	73
5	11	96	64	52	440	86	65
6	11	85	56	66	388	76	58
7	7	74	49	20	322	63	48
8	9	67	44	34	302	59	45
9	4	58	38	42	268	53	40
10	4	54	36	18	226	44	33
11	5	50	33	27	208	41	31
12	5	45	30	49	181	36	27
13	3	40	26	15	132	26	20
14	4	37	25	8	117	23	17
15	2	33	22	3	109	21	16
16	6	31	21	34	106	21	16
17	2	25	17	8	72	14	11
20	7	23	15	24	64	13	10
25	11	16	11	34	40	8	6
30	3	5	3	4	6	1	1
35	2	2	1	2	2	0.4	0.3

First, days were tabulated by burning index, column 1, table 5. Next, the days were cumulated upwards in column 2, and percents calculated in column 3. The values in columns 2 and 3 mean, for example, that 74 days or 49 percent had burning indexes of 7 or more. A similar tabulation of fires was made in columns 4 to 6. However, because 76 percent of the fires (table 4) in District 2 occurred during the assumed 5-hour patrol period, noon to 5 p. m., each value in column 6 was multiplied by 0.76 to give the values in column 7. The figures in this last column mean, for example, that 48 percent of the total number of fires occurred during the 5-hour period on days having a burning index of 7 or more.

Major results of this study are summarized in table 6. In examining the table, it must be kept in mind that the values in it are based on the 5 months having highest fire occurrence, January through April, and December, and on a maximum of 5 hours flying time on any one day. More or fewer months or hours could, of course, have been used but the analysis procedure would have been the same.

Table 6 can best be explained by examining a few paired figures in it. For example, in District 1 had air patrols been made on half the days (50 percent column), flying would have been done on all days having a burning index of 5 or more during which time 58 percent of the fires occurred. Following along to the 100-percent column, it will be seen that had patrols been made on all days there would have been a gain of only 8 percent in number of fires.

Table 6. --Relation between percent of patrol days, percent of fires, and burning index, by districts, Georgia, 1959

District	Percent of patrol days																	
	10		20		30		40		50		60		70		80		90		100	
	BI 1/	Fires	BI	Fires	BI	Fires	BI	Fires	BI	Fires	BI	Fires	BI	Fires	BI	Fires	BI	Fires	BI	Fires
		Percent		Percent		Percent		Percent		Percent		Percent		Percent		Percent		Percent		Percent
1	18	16	12	28	8	38	7	47	5	58	4	60	3	64	2	65	2	65	1	66
2	25	6	16	16	12	27	9	41	7	50	5	62	4	73	2	74	2	75	1	76
3	17	22	13	37	10	44	8	53	7	62	5	66	3	71	2	72	1	72	1	72
4	17	26	11	45	8	53	6	62	5	66	3	70	3	72	2	72	1	73	1	73
5	16	22	13	39	10	49	8	56	7	62	6	68	4	72	2	73	2	73	1	74
6	18	19	13	32	9	42	7	47	6	52	4	65	3	74	2	74	1	74	1	75
7	17	29	12	43	9	52	7	59	5	64	4	67	3	68	2	69	1	69	1	70
8	22	14	14	30	11	44	8	51	7	59	6	64	4	69	2	72	2	72	1	73
9	22	28	16	44	11	53	9	58	6	63	4	67	3	68	2	69	1	70	1	70
10	21	20	14	32	11	45	8	53	6	58	5	63	4	68	2	70	1	70	1	71
State	20	20	13	33	10	44	7	50	6	60	5	64	3	69	2	70	1	70	1	71

1/ BI = Burning Index.

Photo by Georgia Forestry Commission

Georgia Forestry Commission aircraft checks fire area. Twenty small planes fly reconnaissance, augmenting the fire tower network in locating and identifying fires. They are especially useful in checking out smokes to determine whether action by ground forces is necessary.

Aircraft can operate from Georgia's secondary road system, thus acting as eyes for the fire boss. Here the pilot has been called down for consultation with the fire crew to help coordinate the attack plan. He will go back aloft to scout out hot spots and runs and then act as lead plane for the fire-retardant bomber.

In table 6, a pair of values have been underscored for each district which appear to the writer, from inspection, to represent approximately the point of diminishing return. When these pairs are compared, remarkably little difference is seen: the burning index ranges from 4 to 6 units for all districts, and fires from 63 to 68 percent if District 1 is excluded. In short, it seems that air patrol would have been most effective on days with a burning index of 5 or more which would have required flying on 50 to 60 percent of the days. At the risk of excessive repetition, it is emphasized that "effective" refers only to periods of greatest fire occurrence.

Records for one year, such as analyzed in this report, obviously are inadequate for operational guidance. Furthermore, 1959 was a relatively easy fire year in Georgia. More information must be collected and organized in addition to such records as are discussed in this paper before the soundest planning basis for air patrol can be developed. The following are several of the more obvious kinds of information needed:

1. Under what visibility conditions is air patrol needed to supplement fixed detectors to meet detection requirements for a specific area?

2. On the basis of performance records, how much time is saved by ground forces as a result of air scouting of fires that do not require suppression action?

3. During periods of generally low fire occurrence, such as in summer, what is the maximum coverage that can be obtained with air patrol that will meet detection requirements and at what saving in lookout tower operation?

If several years of accurate records were available, some specific guidelines for air patrol could be developed to supplement the fire control manager's judgment. Estimates of probable burning index for the most dangerous part of the day could be obtained from a late morning danger measurement and the fire-weather forecast. These could be interpreted in terms of probability of fire occurrence. When combined with a check of visibility conditions and an estimate of the probability of change in risk, a fairly distinct picture of the fire situation should emerge. The fire control manager should then be able to reach a sounder decision as to the desirability of air patrol on a given day than if he had to rely on experience alone.

SUMMARY

Procedures for analyzing fire and fire danger records for use as partial guides to air patrol have been described. Based only on the relation of burning index to fire occurrence for the State of Georgia in 1959, it appears that:

1. Air patrol would have been most effective on days having a burning index of 5 or more.

2. The most effective flying period would have been between noon and 5 p. m.

3. Patrol would have been required on 60 percent of the days.

4. A little less than two-thirds of the fires occurred during the days and hours stated above.

Similar values are given for each of the ten protection districts in the State. There was relatively little difference among them.

Agriculture - Asheville

Station Paper No. 119 March 1961

Soil Site Index for Georgia Slash Pine

by

Charles E. McGee

U.S. Department of Agriculture - Forest Service
Southeastern Forest Experiment Station
Asheville, North Carolina

Soil Site Index for Georgia Slash Pine

by

Charles E. McGee[1/]
Charleston Research Center

INTRODUCTION

Estimating land value from soil properties is not new; farmers have been buying land on a basis of taste, feel, and color for many years. As forest land cost has increased, however, the need for better methods of estimating its productive capacity has also increased. As a result, much progress has been made in the past 20 years in classifying forest land productive potential on the basis of measurable soil properties. Utilizing this method, the study reported in this paper provides an estimate of the productive capacity of old-field sites in the middle coastal plain of Georgia for slash pine plantations.

FIELD PROCEDURE

Observations of stand and site conditions were taken in 214 slash pine plantations in the middle coastal plain of Georgia. All of the counties in this region were searched for suitable plantations, and study areas were found in all but four (fig. 1). These plantations ranged in age from 8 to 27 years and in site index from 35 to 85 feet at 25 years[2/] (table 1). The plantations included in the sample showed no evidence of growth loss from burning, insects, or disease.

Two soil pits were dug on each plot (fig. 2). Profile measurements were taken from these holes, as well as from supplementary auger borings, so that the average soil conditions found on the site could be described. On each plot, the average height and age were obtained for six dominant or codominant trees growing near the soil observation points.

1/ This publication represents the combined research efforts of the School of Forestry, Duke University, and the Southeastern Forest Experiment Station. Special acknowledgement is due Dr. C. W. Ralston, Duke University, for guidance and advice in this study.

2/ Preliminary site index estimates were made from curves prepared by Robert L. Barnes for Florida slash pine in "Growth and yields of slash pine plantations in Florida." Fla. Univ. School Forestry Res. Rpt. 3. 23 pp.

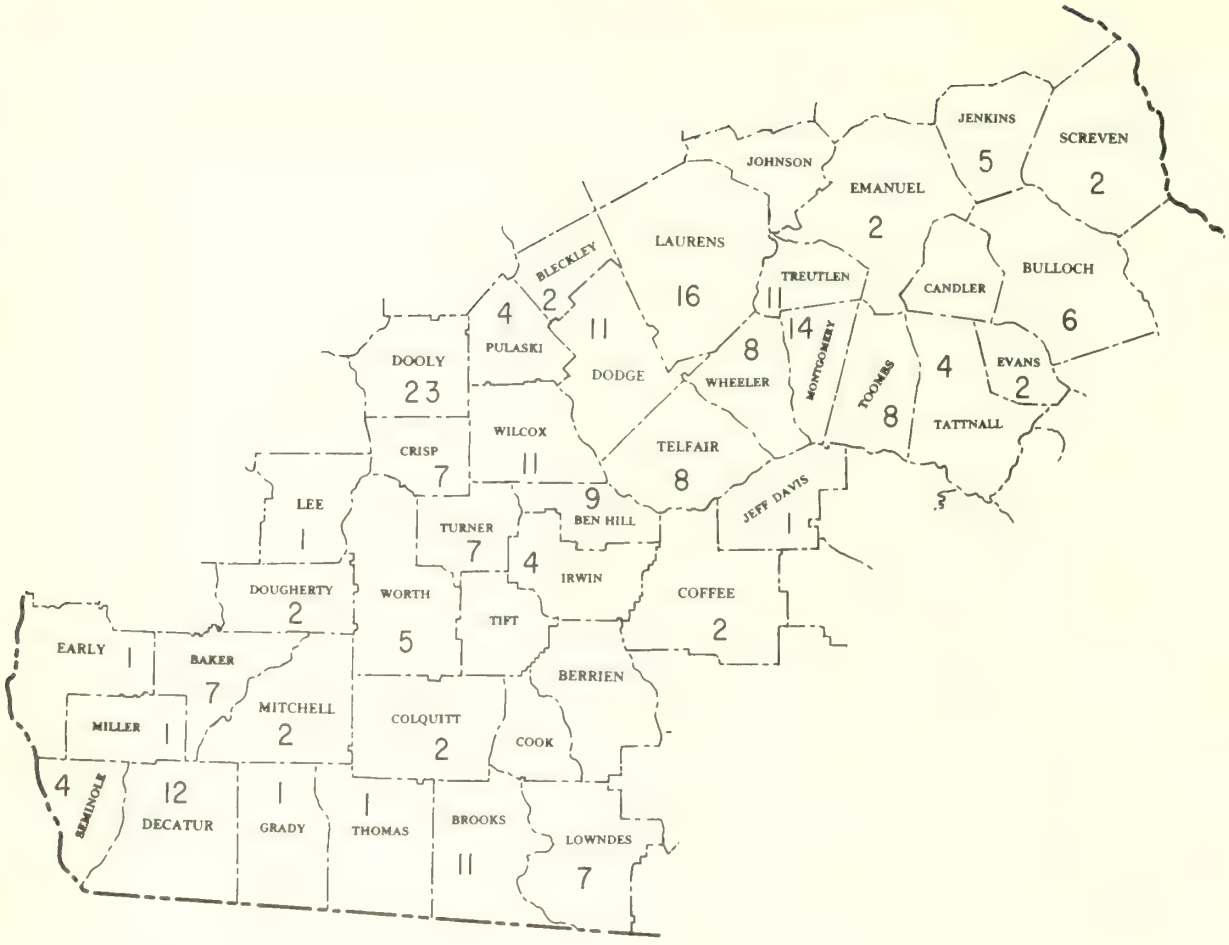

Figure 1.--A map of the Georgia middle coastal plain indicating sample plot locations.

Table 1.--Plot distributions based on age and site index

Age class (years)	Site index class (total height at 25 years)				
	40	50	60	70	80
	Number of plots				
10	0	5	10	34	1
15	4	2	40	61	6
20	0	2	11	30	1
25	2	1	2	2	0
Total	6	10	63	127	8

Figure 2.--Soil profile holes were dug on each plot to measure the thickness of the A_1 horizon and the depth to a fine-textured horizon. Supplementary auger borings were made to check uniformity of the soil characteristics throughout the plot.

STATISTICAL PROCEDURE

The relationship of soil properties to tree height was tested by regression methods. The following equation provided the best estimate of tree heights:

$$\text{Logarithm of dominant tree height (in feet)} = 2.0058 - 5.5907\left(\frac{1}{\text{Age}}\right) + 0.005968\ (\text{thickness of the } A_1 \text{ horizon, in inches}) - 0.1445\left(\frac{1}{\text{thickness of } A_1 \text{ horizon, in inches}}\right) + 0.001837\ (\text{depth to fine texture, in inches}) - 0.000032\ (\text{depth to fine texture, in inches})^2$$

Eighty-seven percent of the variation is explained by this equation, with the soil variables alone accounting for 18 percent of this variation. The error of estimate of a single observation is approximately 10 percent.

The use of the predicting equation as such is too time consuming for normal field use. In order to simplify applications, a table has been prepared that indicates site index at age 25 as estimated from the two significant soil properties (table 2). If tree height estimates are desired at ages other than 25 years, the alignment chart (fig. 3) provides a rapid graphic solution of the regression equation. Note that the age of plantations sampled extended only through 27 years and the data are extrapolated to 50 years. The extrapolated portion of the data should be used with caution.

Table 2.--Soil site index (total height at age 25)

Thickness of A_1 horizon (in inches)	Depth to a fine-textured soil layer (in inches)								
	10	20	30	40	50	60	80	100	110
	Feet								
1	46	47	47	46	45	43	38	33	30
3	57	60	60	59	57	56	50	42	37
6	65	66	67	66	64	62	55	47	42
9	67	70	71	70	67	66	57	49	44
12	--	74	74	73	72	69	61	52	47

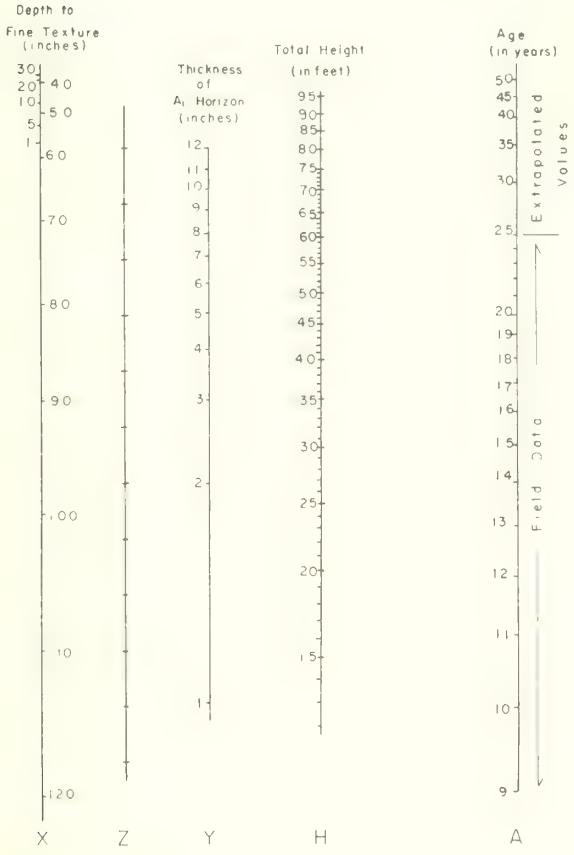

Figure 3.--An alignment chart for estimating height of slash pine. To make a height estimate for an old field:

1. Measure thickness of the A_1 horizon and the depth to a fine-textured horizon.
2. Plot the thickness of the A_1 horizon on line Y, and plot the depth to a fine-textured horizon on line X.
3. Join the points on line X and Y with a straight line and mark the point where the line intersects line Z.
4. Join a line from the point on line Z to the described age point on line A.
5. Read the height estimate from the point of intersection on line H.

APPLICATION OF RESULTS

Several operations are necessary to establish the slash pine growth potential for an area. First, soil sampling procedures must be determined. Sampling points can be established with either a soil auger or post hole digger, depending on the depth and wetness of the soil. As the hole is dug, a record should be made of the thickness of the A_1 horizon and the depth at which a fine-textured soil is reached (fig. 4). A 25-year site-index estimate for the point can be obtained by reading the value in table 2. If the site values for all the points are plotted, a contour map of site indices in the same range can be made.

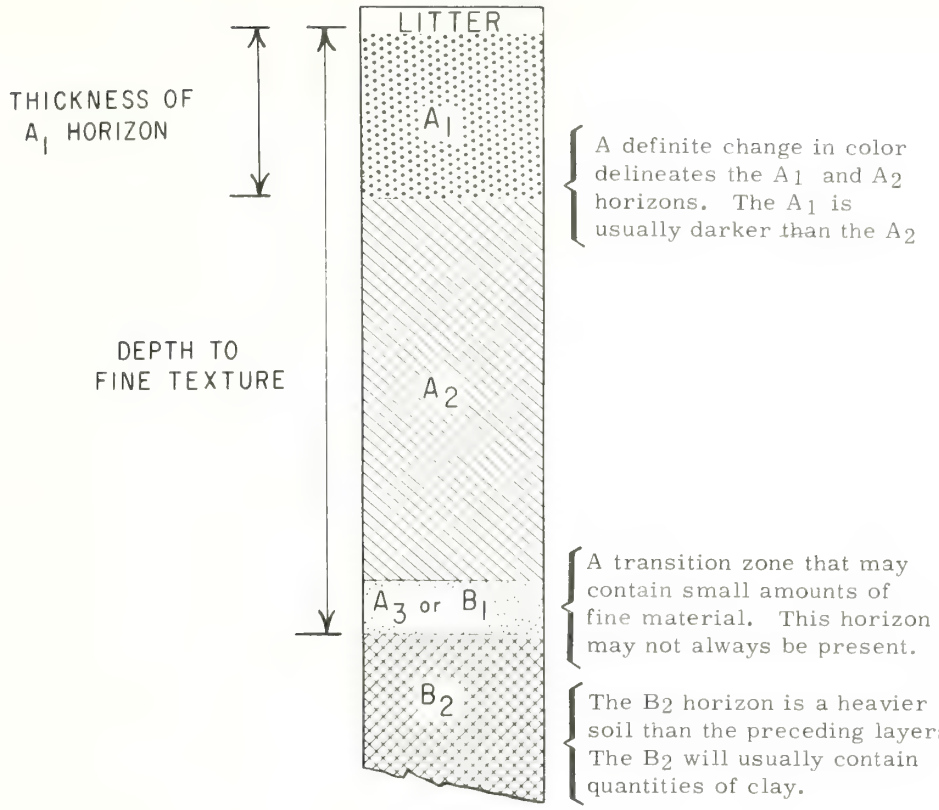
LITTER
THICKNESS OF
A1 HORIZON
A1
A definite change in color delineates the A1 and A2 horizons. The A1 is usually darker than the A2
DEPTH TO
FINE TEXTURE
A2
A3 or B1
A transition zone that may contain small amounts of fine material. This horizon may not always be present.
B2
The B2 horizon is a heavier soil than the preceding layers. The B2 will usually contain quantities of clay.

Figure 4.--A typical soil profile in the middle coastal plain of Georgia.

The A_1 horizon is easy to recognize. It is generally the 3- to 8-inch-thick surface layer of soil. This layer is almost always several shades darker because it contains incorporated or infiltrated organic matter and is sharply delineated from the next layer, or A_2 horizon.

The recognition of a fine-textured horizon can be more difficult. Generally, this horizon will be a subsoil containing a quantity of clay. On the sandy soils, however, this horizon might be a sandy loam or a silt loam. In other words, whenever a clear change to a finer texture is noted, the depth to this point is taken as one of the estimating variables.

The intensity of soil sampling depends upon the local soil variability and the number of site classifications desired. It is suggested that site indices be obtained so that the contour map of site indices classifies sites differing by not less than 10 site index units; i.e., separates site index 40 from 50, 50 from 60, etc.

It is also suggested that soil samples be spaced at the rate of one per acre as a preliminary step. If adjacent samples show a difference in calculated site index of less than 10 units, the sampling intensity can be decreased to one sample per five or ten acres. In cases where extreme changes occur in physiography--or in the soil characteristics themselves--it may be necessary to sample at an intensity of greater than one sample per acre.

A rough estimate of site index can be obtained from table 3 if soil maps are available that supply the necessary soil series information. It should be noted that 142 plots were taken in three soil series (Lakeland, Norfolk, and Tifton) and the variation between plots of the same series is as much as 20 feet at 25 years.

Table 3.--Average site index (at age 25 years) for the soil series examined in the middle coastal plain of Georgia

Soil group	Soil series	Plots	Average site index 1/ (at age 25 years)	Range in site index
		Number	Feet	Feet
Azonal deep sands	Kershaw			
	Old field planting			
	Normal	3	56	43 to 66
	Topsoil removed	2	37	35 to 39
	Forest planting (turkey oak)	7	44	32 to 48
Zonal red-yellow podzolic soils	Lakeland	36	68	58 to 76
	Norfolk	56	69	61 to 81
	Tifton			
	Normal	50	67	60 to 74
	Eroded	2	58	55 to 60
	Ruston	12	68	63 to 74
	Gilead	15	67	61 to 75
	Cuthbert			
	Normal	3	64	60 to 66
	Eroded	3	53	52 to 53
	Orangeburg			
	Eroded	3	56	51 to 59
	Americus	2	66	65 to 68
Interzonal planasol	Susquehanna	2	68	67 to 68
Low humic glei	Blanton	4	73	70 to 75
	Coxville	2	66	64 to 68
	Lynchburg			
	Old field planting	3	69	67 to 72
	Forest planting (gallberry and palmetto)	2	64	62 to 65

1/ Standard deviations for Kershaw old fields ± 7.1, Lakeland ± 4.6, Norfolk ± 5.0, Tifton normal ± 3.3, Ruston ± 3.3, Gilead ± 3.8, and Blanton ± 2.1. The numbers of observations on the other soils were too small to warrant calculation of the standard deviations.

DISCUSSION

The results of this study show that tree heights can be correlated with two specific properties of soil--thickness of A_1 horizon and depth to a fine-textured horizon--which affect soil water, aeration, and nutrient levels. Therefore, interpretation of the present study results should consider how variations in these two properties of the soil affect the moisture and nutrient supply and aeration of the tree.

A look at the alignment chart (fig. 3) shows that an increasing thickness of the A_1 horizon is related to an increase in site quality. The thicker A_1 horizon contains a higher total supply of organic matter and mineral elements. The higher total supply of organic matter also improves the water-holding capacity--an important consideration in sandy soils.

The relationship of the depth to a fine-textured horizon to tree height growth is somewhat more involved. Optimum growth was found on sites having a depth to a fine-textured horizon of 28 to 30 inches. On sites where depth to a fine-textured horizon is greater than 30 inches, moisture becomes limiting because of the poor waterholding capacity of the surface horizons. There also seems to be a tendency for surface soils to become coarser as the depth to fine texture increases. On the shallow sites, where the fine texture is closer to the surface than 28 inches, a number of conditions can develop which adversely affect tree growth. Percolation rates on such sites are apt to be slow, with poor internal drainage and excessive runoff. If the internal drainage is poor, aeration can become a limiting factor to tree growth. If the runoff is excessive, erosion will remove a portion of the A_1 horizon.

Although an effort was made to collect data from poor sites (fig. 5), a large proportion of the sampled areas supported slash pine plantations with site indices of 60 feet or better at 25 years (table 1). The poorer sites were found on eroded phases of the zonal red-yellow podzolic soils or on azonal deep sands. Relatively few plots were taken on these sites because of the limited occurrence of these soil conditions in the middle coastal plain of Georgia.

The plantations sampled were usually on old fields; the few woods plantings that were included were found on deep sands. Therefore, it is important to note that the data in this study applies primarily to old-fields with normal soil profiles.

This study indicates that the work of Barnes and Ralston[3/] was applicable to many of the Georgia middle coastal plain soils. In studying soil factors relating to growth of slash pine plantations in Florida, they showed the following factors to be significant in predicting height growth: reciprocal of age, depth to mottling, depth to a fine-textured horizon, and the silt-plus-clay content of the heaviest horizon. They did not, however, utilize the thickness of the A_1 horizon as a height predicting factor.

3/ Barnes, R. L., and Ralston, C. W. Soil factors related to growth and yield of slash pine plantations. Fla. Agr. Expt. Sta. Tech. Bul. 559, 23 pp. 1955.

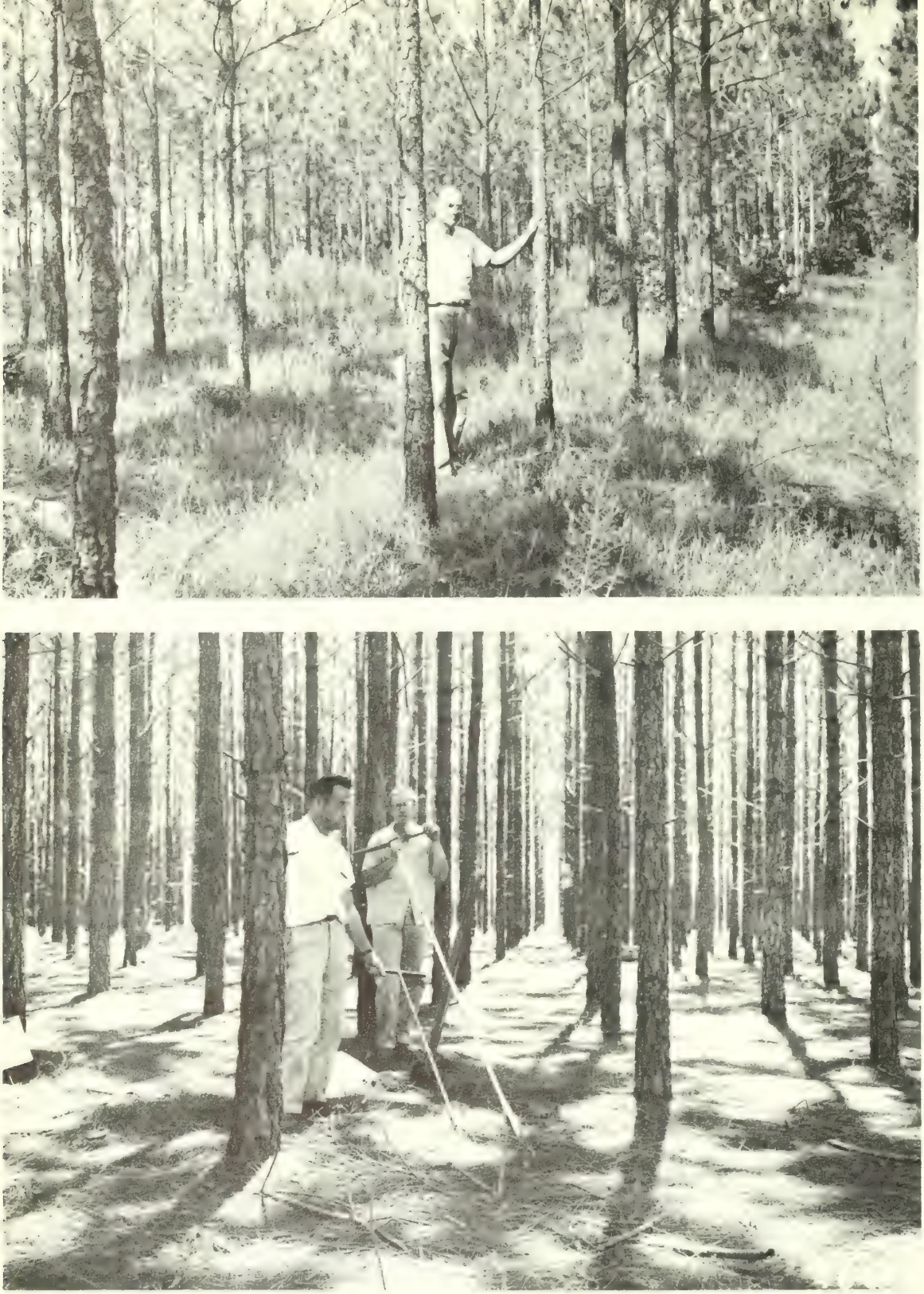

Figure 5. --The plantation on the top is a 13-year-old stand on a deep sand (site class 45). Note that only a few of the larger trees have reached merchantable size for pulpwood. The plantation on the bottom is growing on a site which has a fine-textured subsoil (site index 70) at a depth of three feet and, although only a year older than the plantation on the top, has demonstrated a much greater capacity for growth.

Kreis, Bennett, and Patterson[4/] also tested Barnes' and Ralston's formulation in slash pine plantations in the middle coastal plain of Georgia. Their work indicated that the basic equation of Barnes and Ralston agreed closely with the observed site quality on the deeper soils, and the deviation in height was only 1.4 feet. On shallow soils, however, with a depth of mottling of less than 10 inches, the average deviation was approximately 22 feet.

The present study incorporated plots with shallow and eroded soils, was comprehensive in area coverage, and was restricted to the middle coastal plain of Georgia. In addition, it meets the objections of extrapolating Barnes' and Ralston's work into the study area.

SUMMARY

The purpose of this study was to establish a relationship between soil properties and site index for slash pine plantations in the middle coastal plain of Georgia. In the course of this study, 214 sample plots were established throughout the study area.

The soil properties found to be highly correlated with height growth were the thickness of the A_1 horizon and the depth to a fine-textured horizon. Site quality increases as the thickness of the A_1 horizon increases. Optimum growth was found on sites having a depth to a fine-textured horizon of 28 to 30 inches. On sites where this horizon was shallower or deeper, an adverse effect on height growth was indicated.

For field use of the data, a table and an alignment chart have been prepared to supply a direct height estimate based on the two soil variables. Average site values for the various soil series samples have been calculated and presented in tabular form.

4/ Kreis, E. A., Bennett, F. A., and Patterson, A. E. A site prediction test in slash pine plantations in the middle coastal plain of Georgia. U. S. Forest Serv. Southeast. Forest Expt. Sta. Res. Notes 93, 2 pp. 1956.

Agriculture - Asheville

ation Paper No. 120

May 1961

Control of Honeysuckle and Kudzu

by

E. V. Brender

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Control of Honeysuckle and Kudzu

by

E. V. Brender[1]

HISTORY OF HONEYSUCKLE AND KUDZU

Japanese honeysuckle (*Lonicera japonica* Thunb.) and kudzu (*Pueraria thunbergiana* (S. & Z.) Benth.) were introduced into this country from Asia—honeysuckle for its delicious odor at blossom time, and kudzu for the quick shade it provides for porches. Honeysuckle soon escaped into hedgerows and forests from seed disseminated by birds. Once a honeysuckle seedling becomes established, it also propagates from stolons which on favorable sites spread as much as 15 feet in a year. No wonder honeysuckle today occurs on about 10 percent of the forests in the lower Piedmont of Georgia (Nelson, 1953) and on 8 percent of the forests of Maryland (Bond, 1956).

Kudzu, since it seldom produces viable seed, stayed for a long time confined to the porch. When farmlands and homes were abandoned and neglected, kudzu soon wrapped up houses and trees, spread into fields and woods, but still on a localized scale (fig. 1).

The spread of both vines received an impetus during the Civilian Conservation Corps days when they were planted for roadbank fixation. In addition, kudzu was promoted for gully control, meadow strips, and supplemental pastures. This vine is difficult to confine to allotted areas and when allowed to run wild, which happens on both abandoned and managed farms, the results are spectacular, since some of the runners will grow as much as 30 feet in a single year.

USES OF HONEYSUCKLE AND KUDZU

Honeysuckle has some economic value for winter grazing, and it has contributed to the survival of many cattle during food shortage periods. Kaufman (1950) studied its value as a forage crop and found that cattle gained weight during the first year of summer grazing luxuriant honeysuckle, but succeeding years of grazing resulted in shortened grazing periods and reduced gains in weight. In the fourth year the grazing period lasted only 6 weeks and the gain per animal unit was only 3 pounds, as against a gain of 76 pounds during the first year's 10 months' grazing. This indicates that regrowth of honeysuckle diminished as a result of repeat summer grazing.

Honeysuckle is also valuable as game food, especially for deer browse during the winter months, but the volume of browse available in the Piedmont far exceeds the needs. In fact, honeysuckle seriously interferes with the growth of other browse species.

Kudzu is rich in proteins, and it is rated equal to alfalfa in food value. It provides supplemental summer grazing during drought periods when other forage is short in supply, and as a hay crop, it is very nutritious. Cattle gain weight on a kudzu forage diet, but the species is difficult to manage and can be killed by overgrazing.

[1] Forester, U. S. Forest Service, Southeastern Forest Experiment Station, Macon, Georgia. Work done in cooperation with Georgia Forest Research Council.

Figure 1.—An abandoned house wrapped up in kudzu.

THE PROBLEM

The problem, then, is one of confining honeysuckle and kudzu to specified areas. Either vine forms a dense mat of vegetation, covering everything in its path, smothering shrubs, tree seedlings and saplings, and absolutely inhibiting the establishment of a new crop of trees (fig. 2). Kudzu can climb the tallest trees and smother them (fig. 3), but honeysuckle is the more serious problem. It occurs more extensively and even though eliminated from an area, it can readily re-invade from seed disseminated by birds or flood waters. On some sites honeysuckle control may constitute an ever recurring problem at times of future stand regeneration. In pulpwood-size and larger timber stands honeysuckle does not threaten the overstory trees. Shading and needle cast in well-stocked pine stands keep it in check (fig. 4), but when the stand is opened up by heavy thinning, incipient honeysuckle will spread again (fig. 5).

Kudzu presents a more localized problem. Under proper management, it could be confined to specific use areas. If it is once eliminated from an area, control has been accomplished, and the only way to bring it back is by planting new kudzu crowns.

Figure 2.—A good bottom site capable of growing 2 cords of wood or 600 board feet annually per acre. Unless the honeysuckle is controlled and a new crop of trees established, this area will become non-productive after the present stand is cut.

Figure 3.—(Below) Kudzu smothering a 70-foot loblolly pine tree. Each year kudzu keeps encroaching deeper and deeper into the forest.

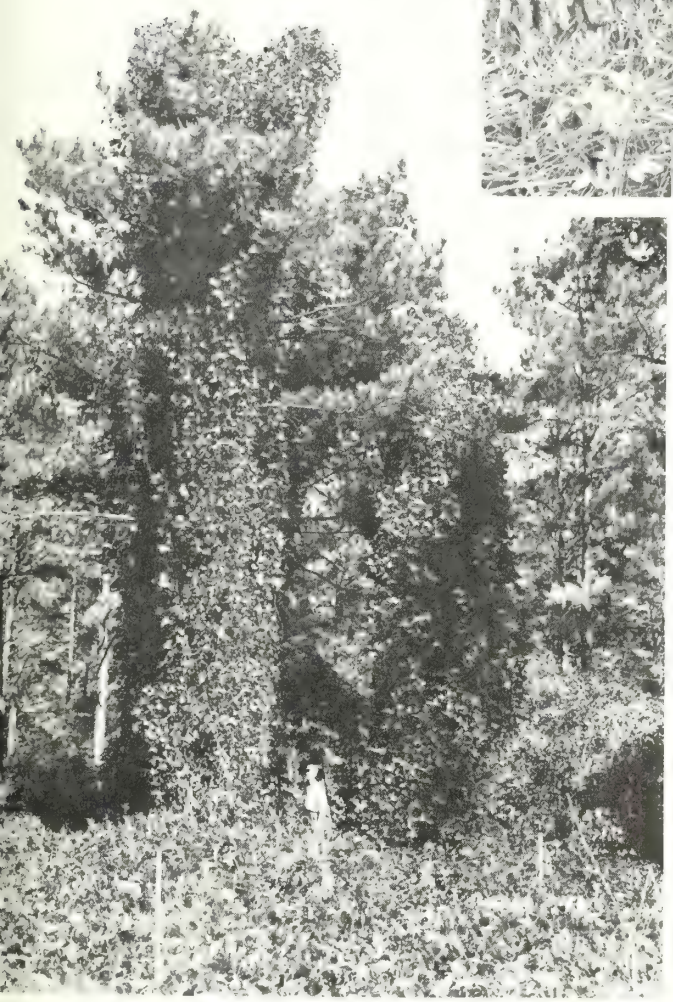

Figure 4.—(Above) In a well-stocked stand of pines, needle cast and shading will temporarily keep honeysuckle in check.

Figure 5.—(Below) In open-grown or heavily thinned stands on good sites honeysuckle takes over, precludes establishment of trees, and chokes out fairly large saplings.

ECOLOGY OF HONEYSUCKLE AND KUDZU

Honeysuckle has become naturalized south of the 30-degree January isotherm and within the 40-inch annual precipitation limit (Leatherman, 1955). This covers the region south from Connecticut, southern Ohio and southern Missouri, and south through eastern Oklahoma and Texas (fig. 6). Honeysuckle thrives on fertile, nitrogen-rich soil, where an established colony spreads in geometric proportions to its perimeter until nitrogen-poor sites are encountered. It grows lush on soils of site index 80 and better for loblolly pine, but on soils of site index 70 and less it is not a serious problem. Honeysuckle spreads vegetatively by layering, the runners developing new roots and shoots at short intervals, and starts growing at temperatures of 34° to 48° F. It has a rather shallow root system that grows to a depth of 6 to 12 inches on moist sites, but on dry sites may penetrate to a depth of 3¼ feet. Branch roots may extend laterally for a distance of 8½ feet. The vine is very drought resistant. Honeysuckle also produces a prolific amount of seed and the requirements for stratification and germination of honeysuckle seed are met under forest conditions of the lower Piedmont. When alternating temperatures of 68° and 86° F. were used in laboratory germination tests, 85 percent of the honeysuckle seed germinated.

Kudzu differs from honeysuckle in many respects. For instance, honeysuckle in the South retains much of its foliage throughout the winter, while the leaves of kudzu are shed after the first frost. Kudzu does not commence growing at such low temperatures as honeysuckle, and it seldom produces viable seed, spreading instead almost exclusively by stolons and rhizomes. Its range probably does not extend as far north as that of honeysuckle. The root system of kudzu is fleshy, and it penetrates much deeper into the soil than honeysuckle, with a taproot that may get as large as 3 inches in diameter and 6 feet in length. Since kudzu is a nitrogen-fixing plant, it can continue to grow — provided it gets established — on much poorer sites than honeysuckle.

Figure 6.—Honeysuckle has become naturalized in the area south of the 30° F. January isotherm and within the 40-inch annual precipitation limit.

CONTROL MEASURES

Any treatment that deprives the vines of summer foliage will weaken them, but to kill the vines the leaves need to be stripped again and again until the energy reserves in the root system are exhausted. Another approach to killing the vines is to tackle the root system directly by mechanical means or possibly through heat generated by burning, or indirectly by applying toxic substances to the foliage for translocation to the roots of the plants. Other approaches might take advantage of all these principles.

During the past 9 years, diversified efforts were made on the Hitchiti Experimental Forest toward finding control measures for honeysuckle and kudzu. Investigations included grazing, burning, harrowing, mulching, the use of herbicides, and certain combination methods.

Grazing

Winter grazing of honeysuckle in the forests, prior to stock laws, was a common practice throughout the South and is still practiced in many farmwoods. Even though cattle stripped all the foliage winter after winter, no honeysuckle has ever been killed from winter grazing. On the Hitchiti Experimental Forest 35 acres of woods covered with dense honeysuckle were fenced and winter grazed by 13 head of cattle for two successive years. After 2½ months' grazing, the honeysuckle was completely defoliated and the runners heavily browsed. During the first year's winter grazing the herd lost 220 pounds in weight, and the cattle had to be moved or they would have starved. By early summer the honeysuckle appeared to be almost as lush as before grazing, and the second year's results were the same.

Summer grazing is probably more detrimental to honeysuckle than winter grazing. As pointed out earlier, four successive years of summer grazing reduced the available forage from 10 months to 6 weeks of grazing at which time the gain per animal unit was only 3 pounds. It would take several more years of summer grazing to eliminate honeysuckle. From a cattle grower's viewpoint, long-term grazing of honeysuckle would not be economical. A few years of summer grazing, however, will weaken the plants and a follow-up treatment with herbicides might finish the job.

Overgrazing of kudzu during the summer months can kill it, but cattle must be kept on it, or brought back to graze whenever a new cover of foliage appears. Two summer seasons of overgrazing, as outlined, will eliminate kudzu except for the vines that are beyond the reach of cattle.

Uses of Fire

Twenty years ago, when the forests of the Piedmont were burned over promiscuously, honeysuckle was far less extensive than it is today. The benefit of wildfire in controlling honeysuckle was in curtailing establishment rather than in controlling established colonies. Fire will burn up the stolons and seed in the duff, and possibly destroy young seedlings and early season root systems that spring from stolons. Soil is a poor conductor of heat and that generated by burning honeysuckle does not penetrate far into the soil. Lush honeysuckle does not burn well; but when pine litter is present, fire will burn through it rather slowly and consume the ground cover of honeysuckle to the bare soil. Honeysuckle will sprout again but somewhat delayed over that following grazing. Fire is a useful pre-treatment for spraying with herbicides, and it can also be used to advantage as a follow-up treatment to spraying. The dead ground cover of honeysuckle burns readily; fire consumes the seed in the litter and exposes future honeysuckle sprigs for mop-up spraying.

Winter burning of kudzu when the leaves are dead is also a good pre-treatment. It not only facilitates later spraying with herbicides, but also exposes the soil to freezing which is detrimental to kudzu rhizomes.

Mechanical Methods

Rank honeysuckle and kudzu form several layers, often waist high, and it is difficult to get complete coverage of the foliage when applying herbicides under these conditions. To reduce these build-up areas and to get a more uniform shallow cover for subsequent spraying when the vines re-sprout, honeysuckle and kudzu areas can be plowed with a heavy-duty tandem harrow. This also facilitates the use of vehicle-mounted power sprayers and makes the area accessible for portable spray machines. But pre-harrowing seems to create a problem of delayed sprouting from stolons and rhizomes buried at various depths. Harrowing after the plants are weakened from herbicide application is a better follow-up treatment than a pre-treatment. In several areas on the Hitchiti

Experimental Forest this combination treatment has been very successful. The use of harrows, however, is limited to open-grown stands.

Sawdust Mulching

Since honeysuckle is intolerant and is a nitrogen-demanding plant, a treatment that deprives it of both light and nitrogen should kill it. Sawdust applied as a heavy mulch will do this. The amount of sawdust needed depends upon the uniformity of the honeysuckle cover; where cover is confined to the ground, a 3-inch layer of sawdust will do the job. A pre-harrowing treatment or a prescribed burn would reduce the amount of sawdust needed. The mulching treatment may be useful in a garden patch.

Use of Herbicides

None of the aforementioned treatments, except mulching, eliminate honeysuckle or kudzu, but they are useful as pre- or post-treatments in conjunction with herbicide applications. Almost any herbicide will strip the foliage from these two vines and, if applied often enough, will kill them the same as continuous summer grazing. Frequent herbicidal applications, however, are not economical. A more adequate treatment that does the job in one or two applications by killing the roots must be found.

Herbicides are selective to some degree, depending upon the structure and growth habits of the plant and the toxicity of the herbicide to the plant. Herbicides are not translocated downward very far for they soon kill the phloem or cambium, and downward translocation stops. But with plants like honeysuckle and kudzu, where the root system is not far removed from the foliage, a short distance of translocation may reach into the roots. Herbicides are most effective if applied at times when environmental conditions and physiological conditions of the plant are right for good growth. Inconsistent results from herbicide treatments are often the result of differences in the growing condition of plants.

Numerous screening tests with hormone and non-hormone herbicides at different concentrations and rates were applied to honeysuckle and kudzu. Different carriers, such as water (with and without wetting agents), kerosene, fuel oil, and non-phytotoxic oil were tried with various herbicides. In the earlier screening tests, knapsack sprayers were used on small plots 33 by 33 feet. It soon became apparent that border effects on small plots obscured the results. Thereafter, 0.1-acre plots were installed and a power sprayer, equipped with hose and adjustable nozzle, was used at pressures of 75 to 100 pounds. This gave a relatively coarse, cone-shaped spray that provided good coverage of the foliage, putting out 150 to 200 gallons per acre (fig. 7). The latest efforts in method of spraying have been directed toward the use of mist blowers.

A total of 19 chemicals were tested in different mixtures with varying degrees of success. Some herbicides merely stripped the leaves but the plants recovered promptly; others gave mediocre control; a few provided satisfactory control in two applications. Those that gave satisfactory control are described for each species of vine, the others are listed in the Appendix.

For honeysuckle.-Where pine regeneration is the objective, honeysuckle needs to be eliminated or weakened so that it cannot regain good vigor before pine reproduction makes a dense shade and needle cast commences.

Application of a mixture of 2,4-D and 2,4,5-T, formulated in butoxy ethanol ester or in isooctyl ester, ratio 2:1, 2 pounds acid equivalent per 65 gallons of water, applied twice during the growing season gives fair control. The first rate of application should be 200 gallons per acre and the second rate 150 gallons per acre. After the first application sprouts are numerous but less vigorous, and after the second application (either in the same or following year) any resprouting consists of weak, chlorotic sprigs. Harrowing at this time will control honeysuckle so that pine seedlings can become established and stay ahead of honeysuckle.

Still more effective is a spray treatment with 3-amino-1, 2,4-triazole, mixed at a rate of 4 pounds per 100 gallons of water, plus 4 ounces of a wetting agent. Depending upon the density of the honeysuckle cover, it takes from 100 to 200 gallons of spray material per acre. This herbicide works more slowly than 2,4-D and 2,4,5-T and is translocated into new sprigs that come up the following year. It interferes with chlorophyll formation; the sprayed leaves of honeysuckle turn pink, then pale and eventually drop off. Still, mop-up spraying is needed the next year, using from 50 to 100 gallons of the mixture per acre. Although not tried, harrowing or burning sometime after the final treatment would probably be desirable. Amino triazole, however, should not be sprayed on lands used for food-crop plants or forage areas (fig. 8).

Figure 7.—Mop-up spraying with a power sprayer and amino triazole of a once lush honeysuckle area.

Figure 8.—The right hand portion of this honeysuckle area was treated with amino triazole. Four months later the foliage was gone and most of the stolons were dead, but a mop-up treatment will be needed.

The very best treatment found to date for control of honeysuckle consists of spraying with 2 pounds of amino triazole and 2 pounds of ammonium thiocyanate (Amitrol-T), mixed at rates of 8 pounds of the mixture per 100 gallons of water, plus 4 ounces of a wetting agent. It takes the same volume to spray an acre as with amino triazole, and the action on honeysuckle is similar except that it is somewhat more thorough. The same restrictions as those for amino triazole alone also apply to the use of Amitrol-T.

A soil sterilant (CMU) gave 100 percent control when applied at rates of 60 to 80 pounds per acre. The cost of this material makes this treatment impractical, and in addition it kills the pine overstory.

For kudzu.-In the control of kudzu, complete eradication is necessary because a single surviving plant will soon cover the ground again—and the tallest trees.

A herbicide application of 2,4-D and 2,4,5-T formulated in butoxy ethanol ester or in isooctyl ester, ratio 2:1, 2 pounds acid equivalent per 65 gallons of water is even more effective on kudzu than on honeysuckle. It takes two applications of 150 to 200 gallons per acre, applied during the growing season when the foliage is full-grown. The second treatment should be applied before other weeds that invariably come in very rank after the first spraying obscure the new sprigs of kudzu.

Although the latest kudzu control measures reflect the results of only one growing season, mist blower application of oil stable 2,4,5-T, 2 pounds acid equivalent, mixed in 4 gallons of non-phytotoxic oil, such as mineral seal oil, and applied at rates of 4 to 5 gallons per acre has given excellent initial results. The first treatment was applied on 0.7 acre in early July 1960, using a portable mist blower. In late September no live kudzu plants were found. Another test at that time was made in exceedingly rank kudzu where access was greatly inhibited (fig. 9) and it was impossible to obtain complete coverage of this kudzu patch in one application. The first application opened things up for a more complete second treatment that was applied in mid-August. Still another kudzu field was treated in early July with a tractor-mounted mist blower. By late September this kudzu field had converted to a dense stand of Johnson grass with very few, widely scattered kudzu sprigs in evidence. When the residue of the dead-appearing kudzu was examined, few live kudzu stolons and rhizomes were found.

The use of non-phytotoxic oil as a carrier has advantages over other solvents. It does not burn the foliage, and because the foliage remains green for several weeks after spraying, the plant functions normally for a longer time, thereby assisting in translocating the herbicides to the roots.

Other advantages of the mist blower method for controlling kudzu are the small volume of mixture needed per acre, the relative ease of applying the spray, and reduced costs.

Figure 9.—Access spraying of rank growing kudzu, using a mist blower with oil stable 2, 4, 5-T (OS) in non-phytotoxic oil. A complete treatment to be given a month later.

SUMMARY

Japanese honeysuckle and kudzu, both introduced from Asia, have spread throughout the South through natural and artificial means until today they constitute major deterrents to regeneration of major forest species. Although they have some economic value for grazing, the problem is one of confining them to specified areas.

Honeysuckle thrives on fertile, nitrogen-rich soil; it spreads vegetatively by layering and sexually by prolific production of seed with a high viability under Piedmont conditions. Kudzu spreads by stolons and rhizomes and, being a nitrogen-fixer, once established it can grow on poorer sites than honeysuckle.

Control studies during the past 9 years include tests of grazing, burning, harrowing, mulching, the use of herbicides, and combination methods. Summer grazing reduces the vigor of both species, but more so for kudzu than honeysuckle.

Controlled burning or harrowing are recommended as pre- and post-treatments to herbicidal spraying of either species.

The most effective herbicide treatment for honeysuckle control consists of spraying with a mixture of 8 pounds Amitrol-T in 100 gallons of water, plus 4 ounces of a wetting agent, applied with a power sprayer at rates of 200 gallons per acre when the honeysuckle puts on new growth in the spring. This herbicide should not be used in food-crop producing or forage areas.

The most effective herbicide treatment for control of kudzu consists of spraying with a mist blower, using a mixture of 1 gallon (2 pounds acid equivalent) oil stable 2,4,5-T in 4 gallons of nonphytotoxic oil, applied at rates of 5 gallons per acre when kudzu foliage is full grown.

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HERBICIDES TESTED ON THE HITCHITI

Herbicide	*Formulation*	*Company Identification*
2,4-D	emulsifiable acid	ACP-638
2,4-D	butoxy ethanol ester	LV-4
2,4-D propionic	butoxy ethanol ester	ACP-685
2,4,5-T	propylene glycol butyl ether ester	Esteron 245
2,4,5-T propionic	butoxy ethanol ester	Weedone
2,4-D and 2,4,5-T		Sherwilkil
2,4-D and 2,4,5-T	butoxy ethanol ester	ACP-977
2,4-D and 2,4,5-T	isooctyl ester	Bramble LV 20-20
2,4-D and 2,4,5-T	tetrahydrofurfuryl ester	Swift 2-2
4 chlorophenoxy acetic acid	butoxy ethanol ester	ACP-903
2 methyl, 4 chlorophenoxy-acetic acid		ACP-904
Polychlorobenzoic acid		Benzac
2,3,6-trichlorophenylacetic acid		Fenac
dimethylamine salt of trichlorobenzoic acid		Trysben 200
2,2-dichloropropionic acid		Radapon
80 percent ammonium sulfamate		Ammate
3-amino-1,2,4-triazole		Amizol
3-amino-1,2,4-triazole and ammonium thiocyanate		Amitrol-T
3-(p-chlorophenyl)-1,1 dimethylurea		CMU

Forced Air-Drying of Southern Pine Lumber

by

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ACKNOWLEDGMENT

This study was made in cooperation with the U. S. Forest Products Laboratory, Madison, Wisconsin, and the George Foster Peabody School of Forestry, University of Georgia, Athens, Georgia. Grateful acknowledgment is made to local lumber companies and dry kiln companies for advice and assistance.

Forced Air-Drying of Southern Pine Lumber

by

L.I. Gaby[1]

Seasoning is one of the most important steps in processing lumber for market. If lumber is air-dried, it becomes the most time-consuming step, often requiring many months and large inventories in order to assure supplies of adequately dried lumber to meet the market at the time required by the buyer.

The rate at which lumber can be dried by conventional air-drying depends almost entirely on the weather, and little can be done to alter the process once the lumber is stacked and placed to dry. The drying season in most localities seldom exceeds six months out of the year because of rainy seasons and cold weather. Fast air-drying occurs only when the periods of high temperatures and low humidities coincide, and this optimum coincidence usually happens during part of spring, summer, and fall. During cold or damp weather it may take many times longer to dry lumber to a satisfactory moisture content; sometimes it becomes impossible to dry to a given final moisture content because of the continual setbacks resulting from intermittent rains.

Degrade is also a problem on the drying yard. Most lumberyard operators expect it on the upper courses of lumber in a pile. Additional degrading occurs down through the pile, depending on stacking method, location, weather conditions, time required to dry certain species, and other factors.

The time and inventory required and the degrade losses involved in conventional air-drying methods are sufficient justification to warrant study on improved processes. Forced air-drying is one method for reducing the drying time, for scheduling drying within predetermined periods of time, and for minimizing degrade. Some forced air-drying is being used by the lumber industry with good results. Drying time has been reduced, flatter and brighter stock is reported, and costs appear to be in line with conventional yard air-drying when the lumber grade savings and improvements are balanced against the time and cost of carrying large inventories of lumber over unpredictable periods.

Forced air-drying of lumber is a method for seasoning green wood (from 30 to 300 percent moisture content) to about 20 percent moisture content by means of forced air circulation with low heat if conditions require

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1/ Technologist, Athens Branch of the Macon Research Center, maintained by the Southeastern Forest Experiment Station in cooperation with the School of Forestry, University of Georgia.

it.[2] One method utilizes large buildings constructed of low cost materials and equipped with large fans, a venting system, and sometimes a means of providing supplemental heat. Air makes one pass through the lumber in unheated buildings, but it is recirculated when heat is used. Another method uses large mobile fans to push or pull air through lumber piles located on the yard, and the air is always at the prevailing yard temperatures and relative humidities.

The primary objectives of this study were to test variables of weather, air velocities, and supplemental heat as they affect the drying of southern pine lumber. Secondary objectives were the determination of the amount of seasoning degrade, the uniformity of moisture content, the relation of air velocities and drying time to fan power consumption, and the effect of length of air travel on drying uniformity and degrade.

TEST EQUIPMENT USED

A small commercial-size dry kiln was used when controlled minimum temperature or controlled EMC[3] conditions were desired (fig. 1). This kiln has a capacity of approximately 6 M board feet. In addition to the usual dry kiln recorder-controller, other instruments were installed for various tests: a wood-element hygrostat[4] to control equilibrium moisture content to maximum set points, a watt-hour meter to measure power consumption of the fan motor, and three additional recorders placed inside and outside the kiln to provide hourly data on temperature and relative humidity. The dry kiln was used for its accurate control features and any reference to tests in the dry kiln refer to forced air-drying.

Information was also taken from three small wind tunnels, constructed to supplement the kiln data and to provide information which could not be obtained in the kiln. Each tunnel is 4 feet square in cross section, and the length can be extended from the basic 8 feet to longer lengths. Ambient air is pulled through the load in the tunnel by a fan 44 inches in diameter without recirculation (fig. 2). An open shed protects the tunnels from rain and permits free movement of air. A hygrothermograph provides a continuous record of temperatures and relative humidities of the air entering the tunnels.

2/ Similar methods are called fan air-drying and predrying. The term "predrying" was coined by the Australians who used this method to reduce the moisture content of lumber to the fiber saturation point (about 30 percent). The lumber was then placed in kilns for final drying.

3/ Wood gives off or absorbs moisture, depending upon the relative humidity and temperature in which it is exposed. The point at which wood neither loses nor gains moisture is a balance point reached with the atmosphere and is known as the wood equilibrium moisture content. It is closely related to relative humidity.

4/ Johnson, Seymour J., and Rasmussen, E. F. A Wood-Element Hygrostat. U. S. Forest Serv. Forest Prod. Lab. Rpt. 1602. 1959.

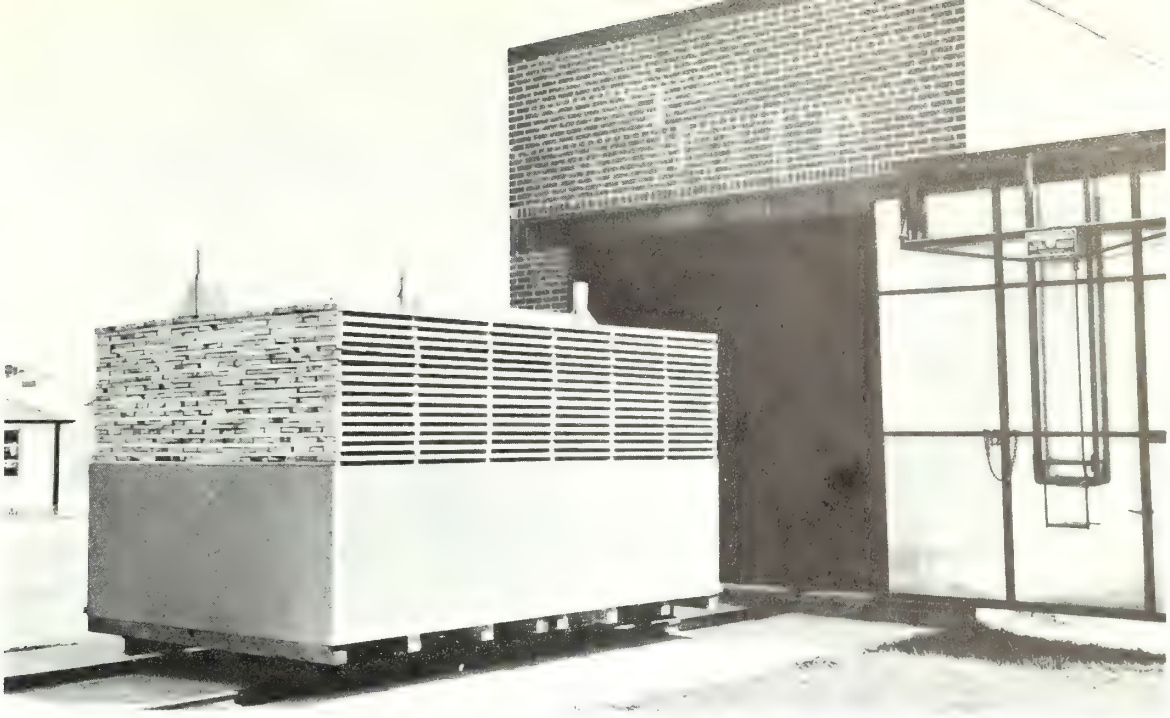

Figure 1.--Load ready for drying in the modified test kiln located at the George Foster Peabody School of Forestry, University of Georgia, Athens, Georgia.

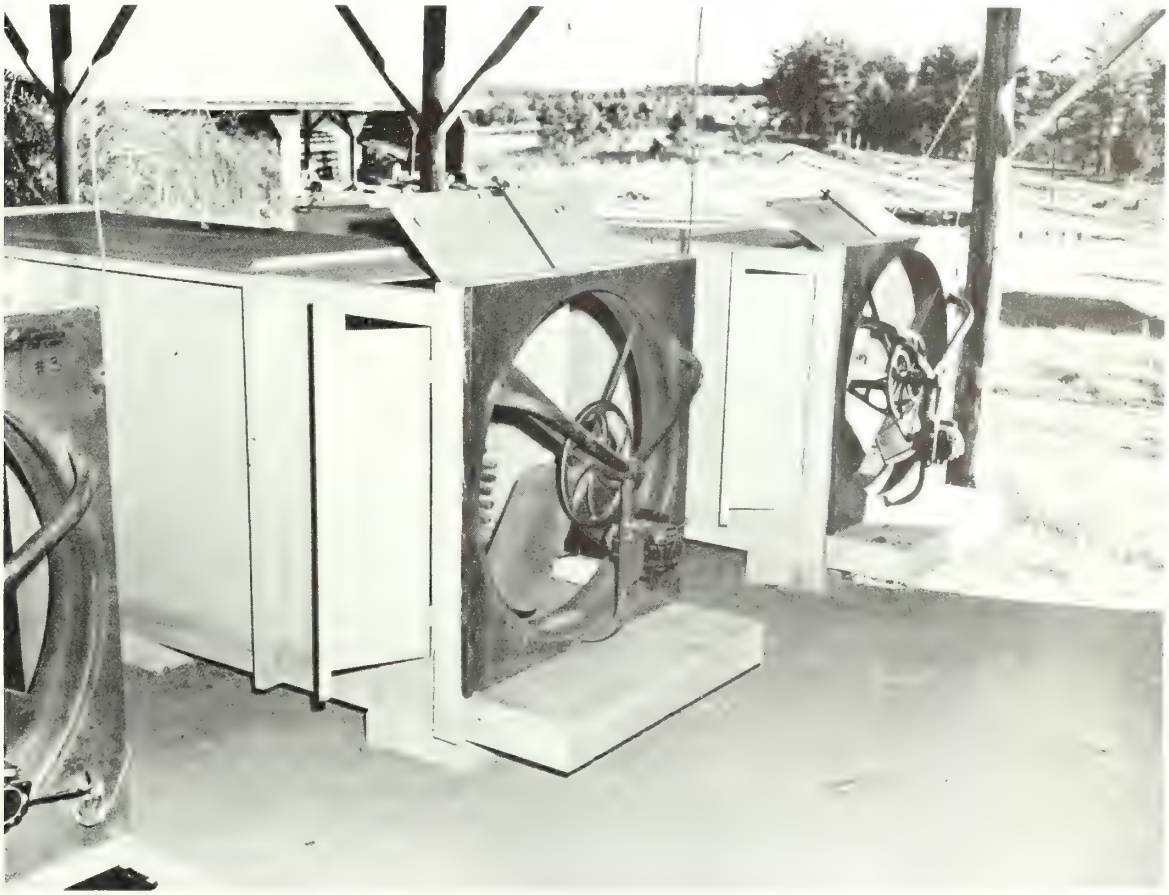

Figure 2.--Experimental wind tunnels for drying tests.

TEST PROCEDURE

Dry Kiln

For tests in the kiln, uniform loads of 15 courses of rough green pine lumber (about 1,300 board feet when using 4/4) were piled on a dummy base to reduce the amount of lumber for a single test. Each course was 8 feet wide and 12 feet long and was made up of 14 or 15 boards. The boards were piled edge to edge on 1-inch-thick stickers placed 2 feet apart.

A minimum of six sample boards was placed in each side of the kiln loads to determine daily moisture content. These samples were selected from the greenest material within thickness limits of 1 to $1\frac{1}{8}$ inches for 4/4, and 2 to $2\frac{1}{8}$ inches for 8/4. In addition to being used for determining daily moisture content, these sample boards were used at the end of the test to check calculated moisture content and final moisture content.

Average air velocities of 200, 600, and 1,000 feet per minute in the kiln were obtained by varying the number of fans (table 1). The actual average air velocity for each test, however, was determined by measuring the velocity in each sticker opening on the air-exit side of the load (fig. 3). Measurements were made with a thermo-anemometer soon after the test was begun in order to adjust for any large differences in velocities. Length of air travel was 8 feet for each test and air direction was reversed every 3 hours.

Table 1.--Typical air velocity variations obtained in kiln tests

Fans used (number)	Range of velocities	Mean velocity	Standard deviation	Coefficient of variation
	Feet per minute	Feet per minute	Feet per minute	Percent
1	120-250	187	22	11.8
2	450-650	573	45	7.9
3	900-1100	994	57	5.7

Tests conducted at a constant 80° F. setting during the fall and winter months in Athens, Georgia, required supplemental heat, whereas little or none was needed during spring and summer. For other kiln tests under equilibrium moisture content control, the temperature was permitted to vary as required to maintain the desired EMC through the use of a wood-element hygrostat. Vents were open continuously during all tests.

Control of the maximum EMC in the kiln was done with a wood-element hygrostat which operates on the principle that wood gives off and absorbs moisture with changes in EMC (fig. 4). These changes cause the wood element to shrink or swell. The shrinking and swelling action is utilized to automatically supply additional heat when the EMC rises above the setting. Maximum EMC was limited in these tests to various percentages ranging from 9 to 13.

Figure 3.--Measuring air speed with a velometer on the exit side of the load in a forced air-drier.

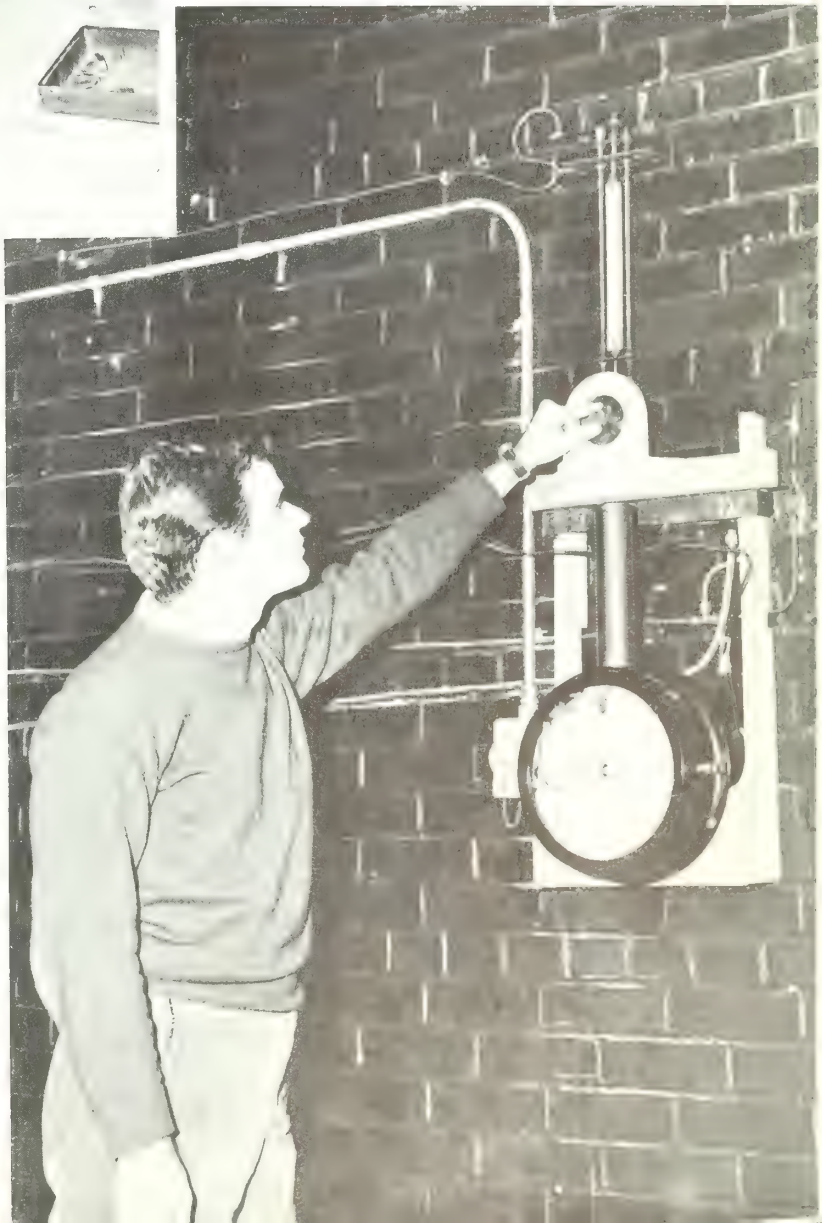

Figure 4.--EMC is controlled by wood-element hygrostat mounted here above the temperature recorder-controller.

During all tests with EMC control, air velocity was maintained at approximately 600 feet per minute.

After each test in the kiln every board was graded twice. In the first round of grading, seasoning defects were ignored; in the second grading, they were considered. Causes for degrade were recorded, according to the limitations specified in the grading rules of the Southern Pine Inspection Bureau.

In addition to the moisture content information obtained from sample boards, the final moisture content of every board in kiln tests was checked with an electric moisture meter. Readings were taken in the center of each board and an average final moisture content determined for each load.

Seven tests were conducted in the kiln at a constant temperature of 80° F. with controlled average air velocities of either 200, 600, or 1,000 feet per minute. Four tests at 80° F. and air velocities of approximately 600 feet per minute were conducted to compare 4/4 and 8/4 lumber dried together. Six tests were made holding air velocity constant at approximately 600 feet per minute and controlling maximum EMC between 9 and 13 percent. Power consumption data was obtained for all tests conducted in the kiln.

Wind Tunnels

No control of temperature, EMC, venting, or recirculation was attempted in the tunnels. Tests were limited to air velocities and length of air travel as they affected drying time.

In the tunnel tests, 22 courses of 4/4 boards 4 feet long were piled edge to edge on 1-inch stickers for the basic 8-foot length of the tunnel. The middle 6 courses constituted the test section and were made up of green lumber. The 2 center courses in the test section contained full-length moisture sample boards and provided all the test data. Two courses above and below the sample courses provided a buffer zone of green lumber to insure that green material surrounded the sample boards.

Sample boards for the tunnel tests were selected in the same manner as those in the kiln tests. Each tunnel contained 2 courses in which every other board was a sample board for a total of 14 samples per tunnel when the basic tunnel length (8 feet) was used. To eliminate differences between sample boards, three 4-foot samples were cut from the same board and distributed among the three tunnels for the same location. The samples were weighed daily and retained at the end of the tests for further analysis.

Air velocities of 300, 550, and 800 feet per minute in the three tunnels were obtained by changing the fan pulley ratios and the air by-pass openings as necessary. Length of air travel tests were conducted in a 16-foot tunnel using a constant air velocity of approximately 500 feet per minute.

The simultaneous testing of drying rates at air velocities of 300, 550, and 800 feet per minute in the three wind tunnels was replicated three times. Two tests were conducted to determine variation in drying rates as affected by length of air travel.

RESULTS AND ANALYSIS

The results of these forced air-drying tests did not disclose any new principles useful in removing moisture from wood, but they did confirm some well known facts and provided data which should permit drying of southern pine in predetermined drying periods for various operating conditions.

Temperature

The drying rate of wood, like that of similar hygroscopic materials, is directly related to the diffusion rate of moisture from the core to the surface. Increasing the temperature of the wood causes an increase in vapor pressure and the diffusion rate is quickened. Low temperatures (i.e., below 70° F.), therefore, cannot be expected to produce fast lumber drying, all other factors being equal. This is well illustrated in the wind tunnel tests conducted during spring and winter.

When 4/4 pine was dried from green to an average moisture content of 25 percent, drying times varied from 4.4 to 7.5 days in the spring months (average 72° F.) to 7.0 to 12.0 days in the winter (average 42° F.). The same air velocities were used both times (fig. 5). During the winter a definite reduction in drying rate took place at about 25 percent, and any attempt to dry below 25 percent moisture content during cold weather without some additional heat is probably not practical for southern pine lumber.

In the kiln tests, with temperature held at 80° F., drying time for 4/4 pine from green to an average moisture content of 17 percent did not exceed 9.5 days for various air velocities tested during all seasons of the year, thus illustrating the importance of a minimum temperature (fig. 6). Drying time for 8/4 pine ranged from 10.5 to 14.7 days when drying to 17 percent using 80° F. temperature control and an air velocity of approximately 600 f.p.m. (fig. 7). This was twice the average drying time for 4/4 pine.

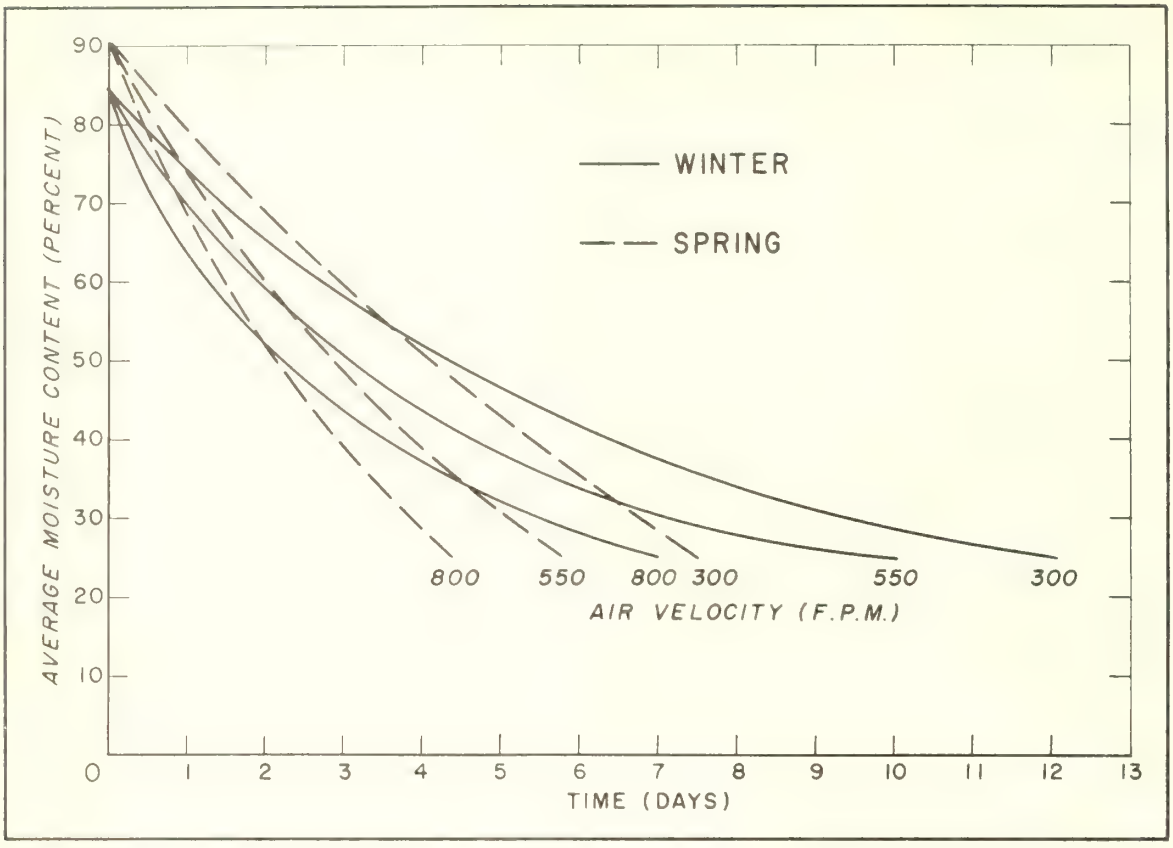

Figure 5.--Effect of air velocity on drying time of 4/4 pine in wind tunnels during spring and winter.

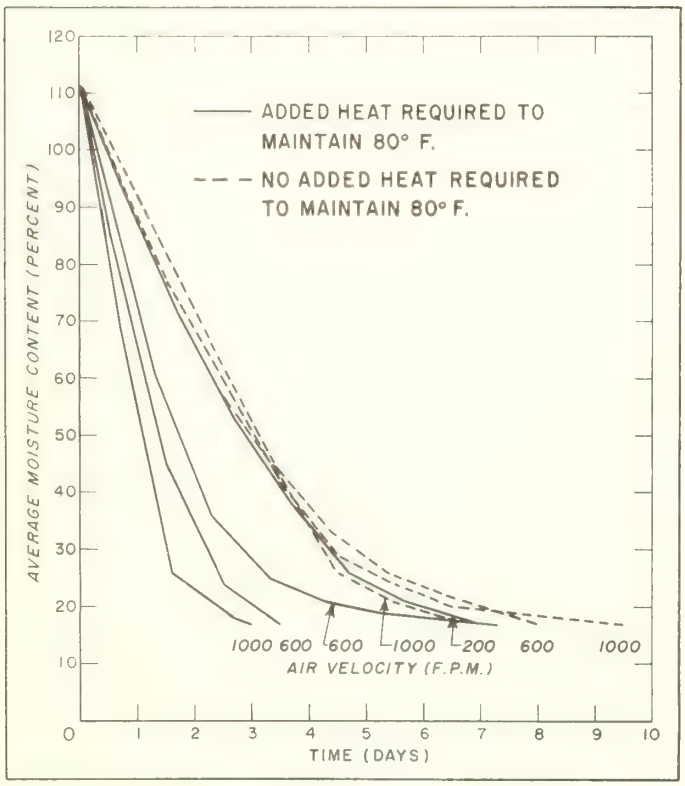

Figure 6.--Pine lumber (4/4) dried at three air velocities and constant temperature (80° F.).

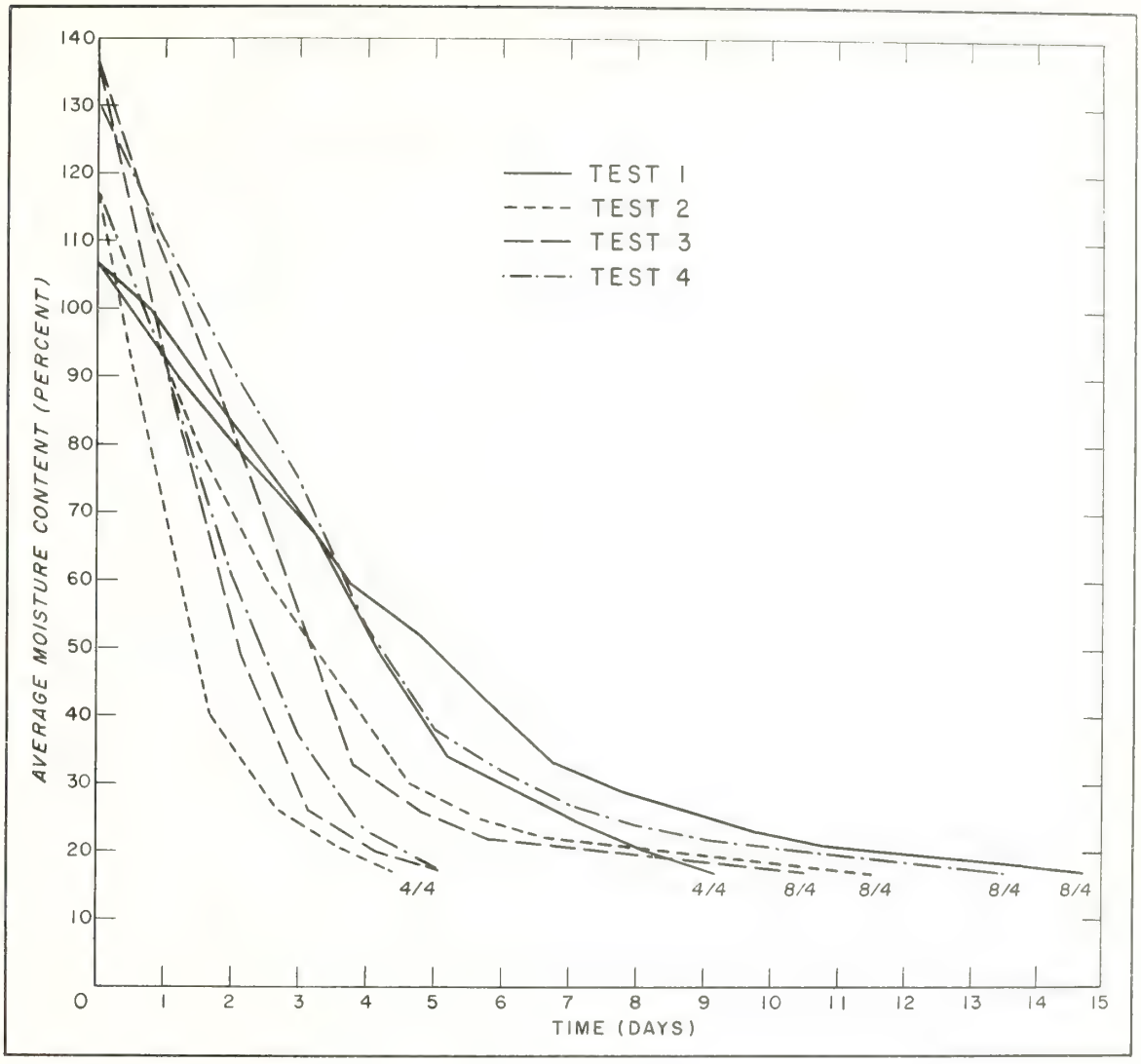

Figure 7.--Pine lumber (4/4 and 8/4) dried together at air velocities of approximately 600 f.p.m. and constant temperature (80° F.).

Drying without additional heat, when outside temperatures are decreasing and drying is slow, is not usually desirable because of the danger of blue stain. This is illustrated in figure 8 by a test in which no heat was added, temperatures were cool, humidities higher than normal because of rain, and with air velocities of 200 f.p.m. Mold appeared on some boards on the sixth day and by the end of the test blue stain degraded 44 percent of the total load at least one lumber grade.

Results in conventional dry kilns clearly show that temperatures of 180° to 200° F. increase drying rates tremendously. Thus, at these temperatures southern pine is kiln-dried commercially from green to 12 to 15 percent moisture content in 3 days. In forced air-drying, however, the objective is to use as little heat as possible in order to keep down the cost of the building, heat-

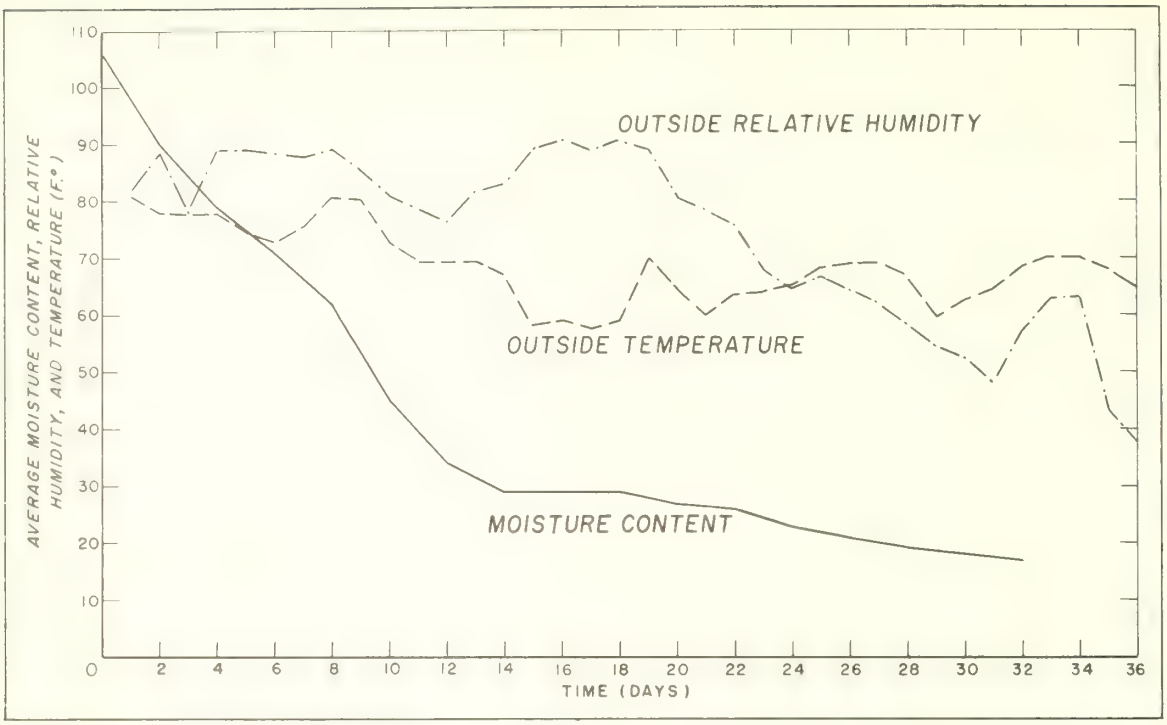

Figure 8.--Pine lumber (4/4) dried in the fall at 200 f.p.m. air velocity in the kiln with no temperature control.

ing facilities, and fuel. The use of temperatures higher than described in these tests (within the limits of necessary humidity control) will speed drying and is limited only by what commercial operators find economical.

Control of Equilibrium Moisture Content Conditions

Air must be partially dry in order to absorb the moisture given off by wood in drying, regardless of air velocities and temperatures. As air approaches saturation, drying slows down or stops. The moisture for saturation can come from the wood being dried or from humid incoming air, or from both. Thus, in order to maintain rapid drying during periods of wet weather, steps must be taken to increase the moisture-holding capacity of the air. This is most easily and economically done by increasing the air temperature so it will hold more moisture. A cubic foot of air at 92° F. will hold twice as much moisture as a cubic foot of air at 70° F. The function of controlling EMC conditions, therefore, is to maintain the drying capacity of the air by adding heat only when necessary. This method is particularly effective and necessary during rainy or humid weather.

Numerous tests made with maximum EMC's of 12.6 percent or less and average air velocities of 600 feet per minute resulted in drying 4/4 pine in 3.3 to 5.5 days from green to an average moisture content of 17 percent (fig. 9).

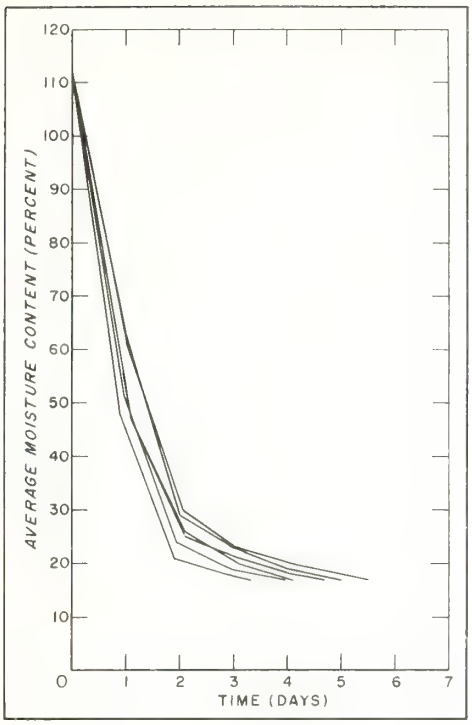

Figure 9.--One-inch pine lumber dried at six EMC conditions from 9.7 percent to 12.6 percent with a constant air velocity of 600 f.p.m.

Temperatures required to maintain a given EMC setting were lower in the winter, and again showed the need for maintaining a minimum temperature in order to assure rapid moisture diffusion to the surface of the lumber, even though the air was dry. To assure adequate air dryness, controls should be set for a maximum EMC of 11 percent and combined with a minimum temperature to provide satisfactory moisture diffusion and evaporation during all seasons.

Air Velocity

Movement of air in the drying of wood is necessary for two reasons: (1) removal of moisture evaporated at the surface of the wood and (2) replacement of the moisture-laden air with drier air so that drying can continue. Drying time is reduced as air velocity is increased up to the point when moisture is being carried away as fast as it reaches the surface.

The effect of air velocities on reduction of drying time is most clearly illustrated in the wind tunnel tests where three velocities were tested simultaneously so as to minimize all other variables. In these tests, air velocities of 300, 550, and 800 feet per minute were used during several seasons (fig. 5). In the spring months the drying times for these air velocities were 7.5, 5.8, and 4.4 days, respectively, from the green condition down to a moisture content of 25 percent. Comparable tests during the winter required 12.0, 10.0, and 7.0 days. These results indicate a reduction of 1 to 3 days drying time per 200 to 250 feet per minute increase in air velocity.

Results of air velocity tests in the kiln showed how fan power required to produce various air velocities was related to drying time. The average daily consumption of electricity was 52, 83, and 148 kilowatt-hours for the average air velocities of 200, 600, and 1,000 feet per minute, respectively (fig. 10). Power consumption was almost doubled when air velocity was increased from 600 to 1,000 per minute, but drying time was not reduced in proportion. Based on these tests the optimum air velocity is approximately 600 feet per minute and is justified by reduced drying time.

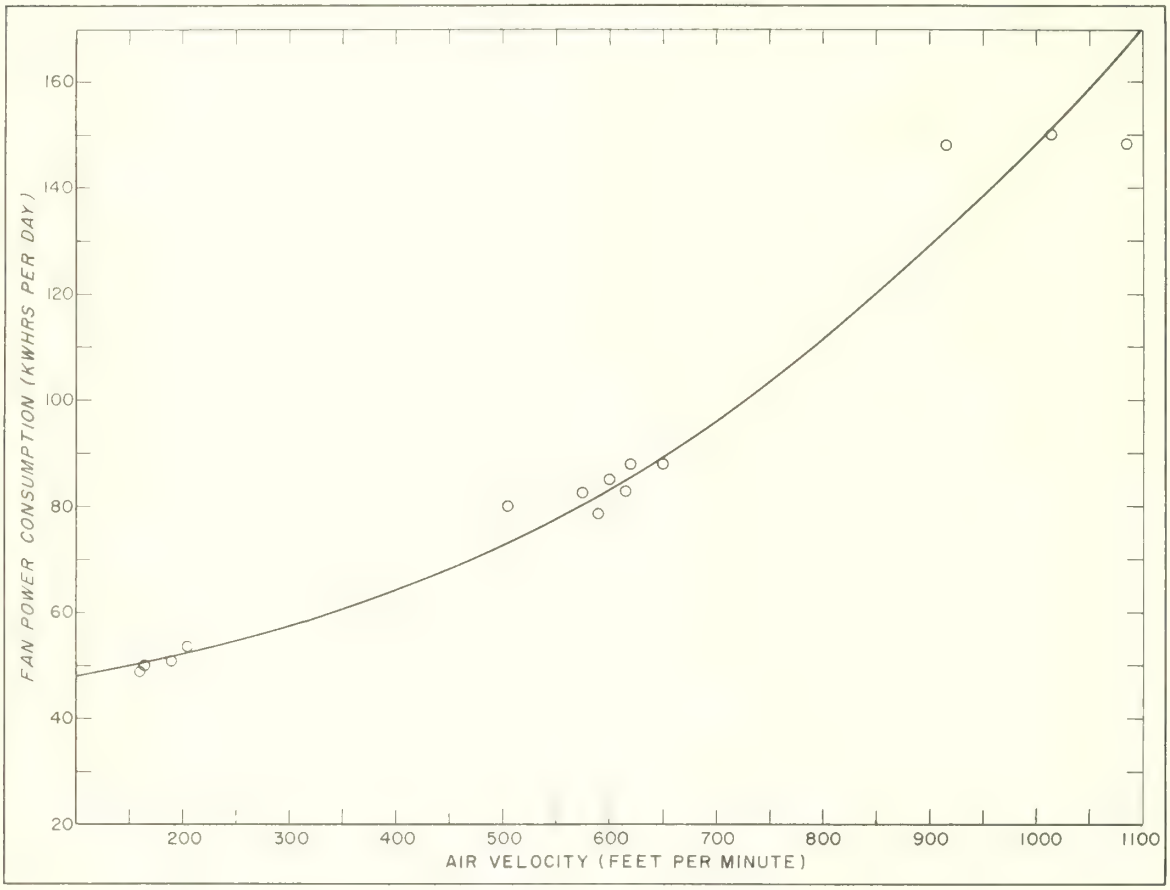

Figure 10.--Fan power consumption at various velocities in the dry kiln.

Length of Air Travel

The past experiences of lumber companies with tunnel-type forced air driers have demonstrated the hazards of structures in which air must travel an excessive distance before leaving the lumber. Air picks up moisture as it moves across the surface of green lumber and progressively loses its capacity for drying. Drying ceases entirely when the air finally becomes saturated. The distance air travels through a lumber load affects the drying time, moisture content uniformity, and degrade from stain.

Tests conducted in an extended wind tunnel revealed important differences in the drying time and condition of boards located at various positions from the air-entry end to the air-exit end. As expected, faster drying occurred at the air-entry end and was progressively slower near the air-exit end. Using a tunnel 16 feet long, with samples placed 8 feet apart at air-entry, center, and air-exit locations, drying time for 4/4 pine was 5.0, 11.3, and 14.3 days, respectively, from the green condition to an average moisture content of 30 percent (fig. 11). No heat was used and an air velocity of 500 feet per minute was maintained without change of direction. It rained on the 5th, 6th, and 7th days and heavy blue stain developed on boards at the air-exit end on the 9th day. Similar results were obtained in the second test using an identical drying setup but with additional sample boards immediately behind the boards at the air-entry side. Rain also occurred during this test beginning on the 4th day and continuing through the 8th day. On the 7th day heavy blue stain appeared on the boards.

Additional samples used in the second test permitted the approximation of maximum air travel and comparable drying rates for the drying conditions at time of test (fig. 12). Using this for illustrative purposes only, the curve permits approximation of calculated moisture contents at any place in the

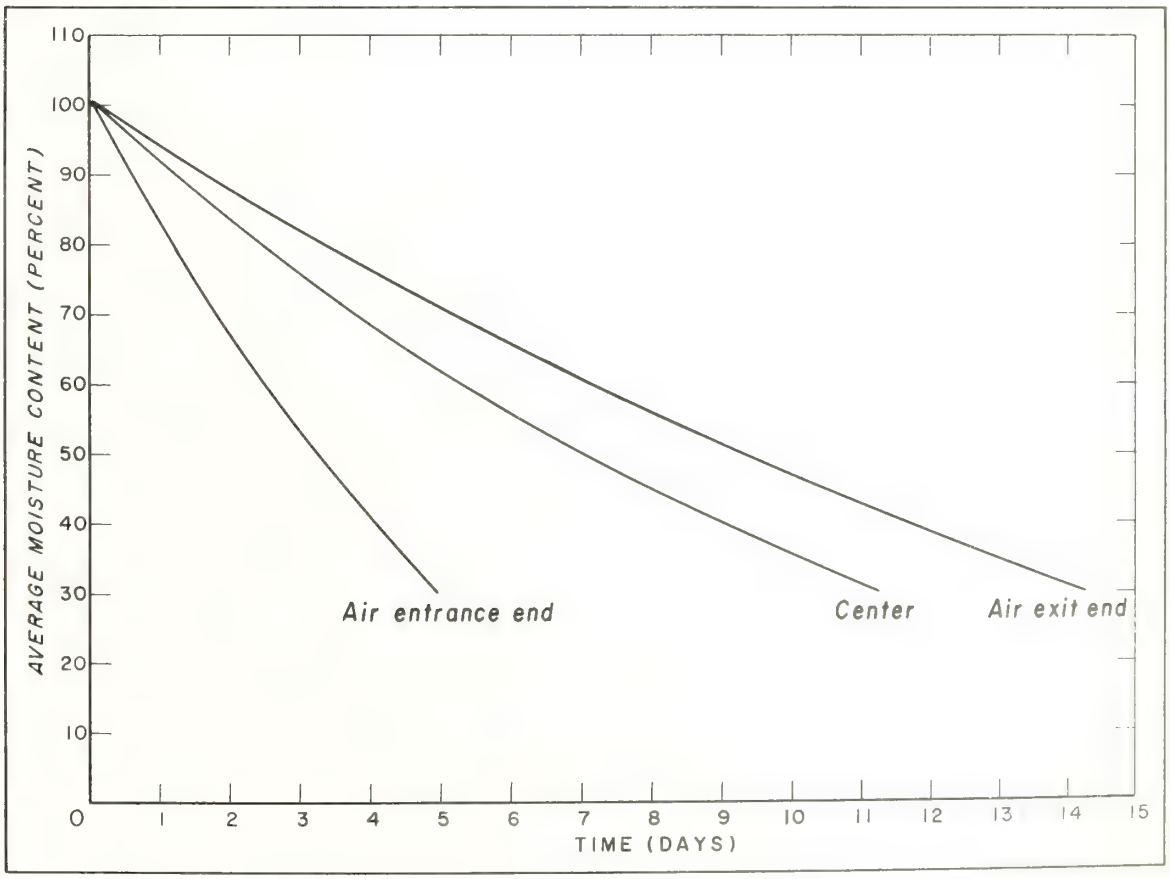

Figure 11.--Effect of length of air travel on drying time of 4/4 southern pine.

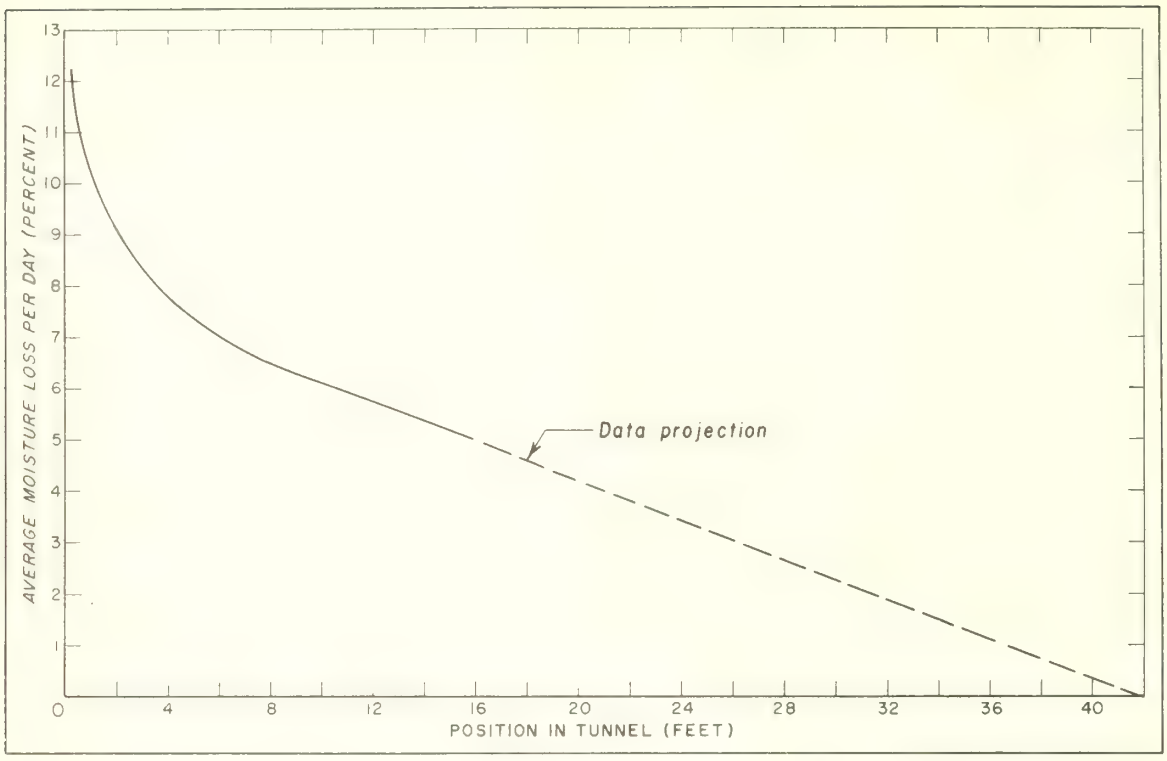

Figure 12.--Effect of length of air travel on drying rates of 4/4 southern pine. Drying time is 8 days. No control of drying conditions except air velocity (500 f.p.m.). No fan reversal.

test tunnel and approximation of the saturation point by extending the data. This test was conducted without heat and with air moving only in one direction.

Based on two tests, it appears that reversing circulation helps eliminate the large differences in moisture content and also reduces drying time. These tests were conducted in the kiln with an 8-foot air travel, with and without air circulation reversal, and resulted in reduced drying time and better moisture content uniformity (fig. 13).

Seasoning Degrade

Seasoning degrade in conventional yard drying can be expensive. Research conducted recently in Georgia indicates that the average loss resulting from all seasoning degrade in drying 4/4 pine was approximately $10 per thousand board feet and varied from $5 to $26 per thousand board feet, depending on the stacking method used.[5/]

5/ Page, Rufus H., and Carter, Roy M. Heavy Losses in Air-Seasoning Georgia Pine and How to Reduce Them. U. S. Forest Serv. Southeast. Forest Expt. Sta. Paper 85, 20 pp., illus. 1957.

Results in the kiln and tunnel tests indicate that much of this loss can be eliminated by forced air-drying so long as the variables tested in this study are controlled as recommended. Ninety percent of the boards used in these tests were of the common grades described in the rules of the Southern Pine Inspection Bureau. Based on the total number of boards dried, seasoning degrade did not exceed 55 cents per thousand board feet in any test in which drying conditions were controlled. Degrade was not increased by the higher air velocities (tables 2 and 3).

Blue stain occurred in both dry kiln and tunnel tests when dried without control of drying conditions during rainy periods. In the most severe case, 44 percent of the boards were degraded because of blue stain.

Table 2.--Summary of lumber grade before and after forced air-drying southern pine

Lumber grade	Before	After
	Board feet	Board feet
B and Better	312	282
C	534	528
No. 1 Common	11,916	11,784
No. 2 Common	3,402	3,492
No. 3 Common	978	1,050
No. 4 Common	--	6
Total	17,142	17,142

Table 3.--Degrade loss in forced air-drying southern pine

Type of degrade	Amount per M bd. ft.
	Dollars
Surface checks	0.10
End checks	.10
Stain	.14
Crook	.14
Cup	.07
Average loss	.55

Moisture Content

Moisture content is an important factor in the marketing of southern pine lumber. Control of drying conditions will permit forced air-drying of 4/4 lumber to a maximum moisture content of 19 percent in 6 days or less. Dimension material, of course, requires about twice this time to reach 19 percent. Green lumber going into the dryer usually varied in moisture content from 60 to 130 percent (fig. 14). Tests in the kiln were terminated after the wettest sample board dried to 20 percent moisture content with the average final moisture content for most of the 4/4 loads usually 16 to 17 percent. Ninety-five percent of the 4/4 lumber dried under test conditions in the kiln was 20 percent moisture content and less (fig. 15). The moisture content meter readings for all 4/4 loads varied from an average minimum of 12 percent to an average maximum of 19 percent, with individual loads ranging from a minimum of 8 percent to a maximum of 25 percent.

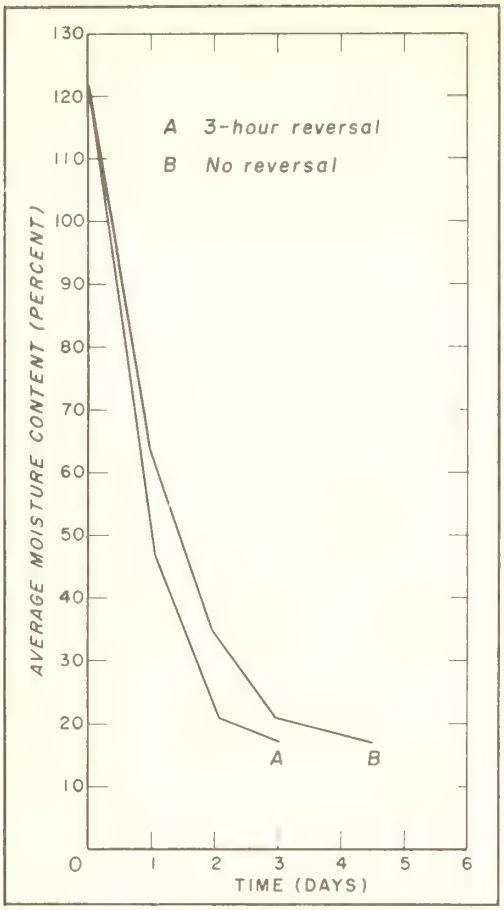

Figure 13.--Effect of air circulation reversal on drying time and moisture content of 4/4 pine lumber, both tests conducted at same EMC control conditions.

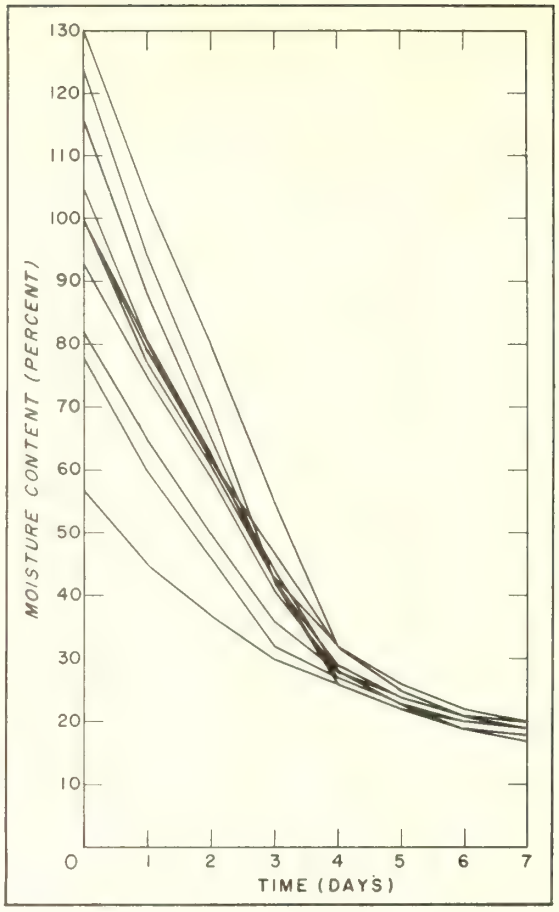

Figure 14.--Moisture-time curves of samples in a typical test illustrating the variation of moisture content. Pine (4/4) dried at 80° F. and 1,015 f.p.m. air velocity.

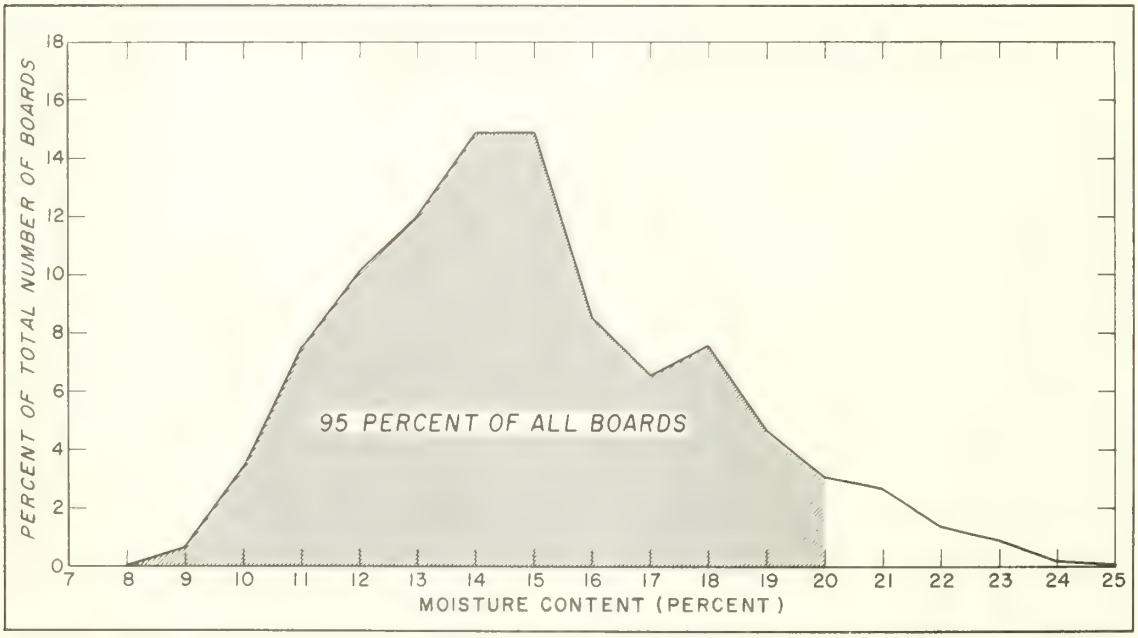

Figure 15.--Frequency distribution of all moisture meter readings (3,080 - 4/4 boards).

CONCLUSIONS

Rough, green, southern pine lumber can be rapidly dried using forced air circulation without significant degrade when drying conditions are controlled. If minimum temperatures, EMC conditions, air velocities, and length of air travel are controlled, 4/4 pine can be dried to 19 percent moisture content in 4 to 6 days. Dimension of 8/4 thickness requires an average of twice as long to dry as 4/4 lumber.

Temperature.--Moisture movement within wood increases as temperature is increased. In order to obtain a satisfactory drying rate, certain minimum temperatures must be maintained. Tests indicate that good drying rates may be obtained when using a constant temperature of 80° F. Higher temperatures (up to 110° F.) can be expected to further reduce drying time without increasing degrade. The use of temperatures higher than 80° F. is desirable and limited only by what the operator finds economical. During favorable spring and summer weather good drying can be done without temperature control. During the fall, when outside temperatures are going down, control of minimum temperatures is a necessary safeguard against slow drying and subsequent blue stain. Drying southern pine lumber below 25 percent moisture content without heat in cold weather appears impractical.

Control of EMC.--Control of maximum equilibrium moisture content is necessary to assure rapid evaporation of wood moisture from the surface of the wood. This type of control must be combined with minimum temperature control in order to be effective during all seasons. EMC control loses its effectiveness during cold weather without minimum temperature control because the ambient temperatures may not be high enough for good moisture diffusion. Equilibrium moisture content control is most effective in the warm months when temperatures are usually already high enough for good diffusion. To assure good drying conditions, maximum EMC control should be set at about 11 percent for pine.

A combination minimum temperature-maximum EMC control in one unit is highly desirable. This would provide more flexibility and require less attention than separate control instruments.

Similar control of EMC might be accomplished by maintaining an inside temperature of 10 to 15 degrees above outside temperatures. Although this method has not been tested, the temperature increase should establish desirable EMC conditions during all kinds of weather. In the winter months minimum temperature control (about 80° F.) would also be necessary for good diffusion. Even in the warm months, this method of EMC control should never require temperatures over 115° F. in any part of the southern pine region.

Air velocity.--Sustained air velocity is essential to the drying process in order to take away moisture evaporated at the surface of the lumber and to replace the moisture-laden air with drier air. Drying time was reduced 1 to 3 days per increase of 200 to 250 feet per minute air velocity up to 1,000 feet

per minute, the maximum velocity tested. Velocities ranging from 200 to 1,000 feet per minute are progressively more satisfactory, with the higher velocities providing better uniformity of air movement and reduced drying time. Large variations in air velocities within the same building are not desirable because of the uneven drying which results. Baffling should be used to get satisfactory air velocities and uniform air movement through the lumber. Comparisons of drying time, power consumption, and air velocities indicate that good economical drying can be done using an air velocity of approximately 600 feet per minute. The use of higher air velocities is not economical because power consumption is too high for the small additional reduction in drying time.

Length of air travel.--As air travels across a load of lumber it picks up moisture and its capacity for drying is reduced. If the air travel is excessive the air becomes saturated before it leaves the load and no drying takes place. Control of length of air travel through the load is definitely necessary to maintain good EMC conditions, insure moisture content uniformity, reduce danger of blue stain, and decrease drying time. Length of air travel can cause large differences in drying time, moisture content, and degrade. The need for caution in constructing driers in which air must travel a long distance cannot be emphasized too strongly.

Seasoning degrade.--Seasoning degrade is a minor factor when EMC is controlled during periods of prolonged high humidity in drying. Without heat during these periods the danger of degrade from blue stain remains until the wood moisture content is approximately 20 percent. Grade losses in pine from conventional methods of air-drying can be reduced to a minimum by forced air-drying under controlled conditions.

Moisture content.--Control of drying conditions in forced air-drying will assure scheduling of drying to meet moisture content specifications (such as 19 percent) within short drying periods (4 to 6 days). Moisture content uniformity can be expected to be better than conventional yard drying.

Building construction and equipment.--Details of the type of building and equipment indicated by this study for satisfactory and economical forced air-drying are problems of engineering. The main features which should be considered, however, are: (1) a low-cost building of pole construction with wood sheathing; (2) large movable vents permitting open operation during favorable outside conditions; (3) large fans capable of 600 feet per minute air velocities through the load; and (4) a heating unit capable of maintaining minimum temperature of 75° F. in cold weather and temperatures of at least 10° F. above outside temperature in warm humid weather.

Economics of Forced Air-Drying

When the cost benefit factors of forced air-drying lumber are studied thoroughly, it will be seen that this method has many advantages over conventional yard air-drying. Some of these factors are tangible, and their cost

or value can be determined readily in terms of dollars and cents. Many of the intangible benefits, however, are equally as important but cannot be evaluated easily in terms of money. These intangible benefits, as reported by companies already using forced air-driers, are:

1. Reduced capital investment by reducing lumber inventories.

2. Greater inventory turnover and thus more profits.

3. Reduced yard space needs.

4. Dependable timing to meet fluctuating market conditions.

All these benefits are associated with the rapid drying which can be done in forced air-driers. Brighter, flatter lumber with less seasoning defects is also one of the main benefits.

The factors which can be determined for 4/4 pine are the cost of forced air-drying, and the savings in seasoning degrade when compared with conventional yard air-drying. Limited data, obtained in operating a pilot plant commercial forced air-drier indicate that operating costs (fan power, heat, and labor) would vary from $1.26 per M bd. ft. for fan drying to $4.50 using fans and heat full time.

This pilot plant drier is an uninsulated wooden structure with a capacity of 30 M bd. ft. (fig. 16). Cost of the structure and equipment is approximately $10,000. Electric power consumption for fan drying is 21 kw.-hrs. per hour and 25 kw.-hrs. per hour when the fans and heater are used. Local commercial rate is $1\frac{1}{4}$ cents per kw.-hr. Fuel consumption is 5 gallons per hour of Number 2 fuel oil. Local bulk rate is $12\frac{1}{2}$ cents per gallon. Unit costs in other areas may change the operating costs.

Figure 16. --Commercial forced air-drier built of pole and siding construction at Athens, Georgia.

Annual drying capacity of the drier is approximately 1,380 M bd. ft. based on 46 weeks operation. Annual labor required amounts to approximately 400 man-hours at $2.50 per man-hour. Maintenance and repair are set at approximately $0.05 per M bd. ft.

Cost Estimates Based on 30 M Bd. Ft. Capacity and 6-Day Schedule

Fixed cost:

Depreciating $10,000 at 6 percent in equal payments in 10 years	= $0.98/M bd. ft.
Maintenance and repair	= .05/M bd. ft.
Total	= $1.03/M bd. ft.

Operating cost:

1. When only fans are needed--electricity costs:
   6 days x 504 kw.-hrs. x $1\frac{1}{4}$ cents/kw.-hr. = $1.26/M bd. ft.

2. When fans and heat are needed--electricity and fuel costs:

6 days x 600 kw.-hrs. x $1\frac{1}{4}$ cents/kw.-hr.	= $1.50/M bd. ft.
6 days x 120 gallons x $12\frac{1}{2}$ cents/gallon	= 3.00/M bd. ft.
Total	= $4.50/M bd. ft.

In order to determine the gross drying cost, fixed costs must be added to operating costs. Fixed costs include depreciation of the structure and equipment plus an amount for repairs and maintenance. These fixed items amount to $1.03 per M bd. ft. for the pilot plant drier and brings the gross drying cost to $2.29 per M bd. ft. for fan drying and $5.53 per M bd. ft. using fans and heat full time.

These figures must be deducted from the seasoning degrade savings in order to make a complete comparison. Degrade losses from conventional methods of air-drying southern pine have been found to average $10 per M bd. ft. while the forced air-drying losses averaged only $0.55 per M bd. ft., a difference of $9.45 per M bd. ft. The difference between $9.45 and the gross drying cost above indicates that $3.92 to $7.16 per M bd. ft. can be saved in degrade alone by forced air-drying as compared to conventional yard air-drying.

Since these calculations are based on the performance of an uninsulated structure of minimum commercial size, costs probably would be less for a more efficient structure with greater capacity. However, the savings are sufficient to warrant consideration by the progressive lumberman interested in drying on a rapid schedule with minimum seasoning losses.

tion Paper No. 122 June 1961

A Method of Appraising Pine Sawtimber in South Carolina

by

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ACKNOWLEDGMENTS

The author wishes to thank the Management Branch of the South Carolina State Commission of Forestry and the individual district offices for supplying the data used in this study. He also would like to express his appreciation to Miss Sheila McCabe of the National Weather Records Center for calculations she performed on electronic computing equipment which made possible the selection of optimum estimating equations.

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Division of Forest Economics Research

INTRODUCTION

Every forest landowner who offers his standing trees for sale must answer the question, "How much is my stumpage worth?" Few, especially among the small owners, can make a reasonable estimate.

One reason owners find it difficult to appraise their timber is that they must sell it in an unorganized market where there is no going price to guide them. But even when they know the prices being paid for other tracts, this knowledge is slight help by itself because timber prices vary widely according to the size of trees, distance to mill, and other characteristics.

Professional appraisers have found ways of overcoming these difficulties in practice. One way has been simply to gain enough experience and knowledge of the market to be able to set prices through judgment. Another, and more objective way, has been to use one of the standard appraisal procedures such as the overturn method. Unfortunately, the small landowner can use neither. He sells too infrequently to develop the sense of value that comes from comparing the price paid for one tract with that paid for another. And he finds the standard procedures are complicated and require data unavailable to him. What the occasional seller of small lots of timber needs is a simple appraisal method. This paper describes such a method which is applicable to marked pine sawtimber in South Carolina.

HOW TO ESTIMATE THE MARKET VALUE OF AN INDIVIDUAL TRACT

Using the State Average Price

In South Carolina, the price paid for a stand of marked pine sawtimber depends upon: (1) The average price being paid for pine sawtimber throughout the State, (2) the average volume per marked tree, (3) the road distance to the nearest stationary sawmill or planing mill, and (4) the geographic location of the woodland within the State. With this information, an owner can work out the market value of his tract if he will sell it as foresters advise, i.e., has his stand marked and cruised and endeavors to obtain at least three bids. Using tables 1 and 2, the only figuring necessary is one addition or subtraction. All volumes and values are in terms of Scribner scale.

Table 1. --Basic price per thousand board feet, Scribner, by State average price and average volume per tree

(In dollars)

State average price (Dollars per M bd. ft.)	Average volume per tree (board feet)													
	40	60	80	100	120	140	160	180	200	220	240	260	280	300
20	15.60	16.00	16.50	16.90	17.30	17.80	18.20	18.70	19.10	19.60	20.00	20.40	20.90	21.30
21	16.60	17.10	17.60	18.00	18.50	18.90	19.40	19.90	20.30	20.80	21.30	21.70	22.20	22.60
22	17.70	18.20	18.70	19.10	19.60	20.10	20.60	21.10	21.60	22.00	22.50	23.00	23.50	24.00
23	18.70	19.20	19.70	20.20	20.80	21.30	21.80	22.30	22.80	23.30	23.80	24.30	24.80	25.30
24	19.80	20.30	20.80	21.40	21.90	22.40	22.90	23.50	24.00	24.50	25.00	25.60	26.10	26.60
25	20.80	21.40	21.90	22.50	23.00	23.60	24.10	24.70	25.20	25.80	26.30	26.80	27.40	27.90
26	21.90	22.40	23.00	23.60	24.10	24.70	25.30	25.90	26.40	27.00	27.60	28.10	28.70	29.30
27	22.90	23.50	24.10	24.70	25.30	25.90	26.50	27.00	27.60	28.20	28.80	29.40	30.00	30.60
28	24.00	24.60	25.20	25.80	26.40	27.00	27.60	28.30	28.90	29.50	30.10	30.70	31.30	31.90
29	25.00	25.60	26.30	26.90	27.50	28.20	28.80	29.40	30.10	30.70	31.30	32.00	32.60	33.30
30	26.00	26.70	27.30	28.00	28.70	29.30	30.00	30.60	31.30	32.00	32.60	33.30	33.90	34.60
31	27.10	27.80	28.40	29.10	29.80	30.50	31.20	31.80	32.50	33.20	33.90	34.60	35.20	35.90
32	28.10	28.80	29.50	30.20	30.90	31.60	32.30	33.00	33.70	34.40	35.10	35.80	36.50	37.30
33	29.20	29.90	30.60	31.30	32.10	32.80	33.50	34.20	35.00	35.70	36.40	37.10	37.90	38.60
34	30.20	31.00	31.70	32.40	33.20	33.90	34.70	35.40	36.20	36.90	37.70	38.40	39.20	39.90
35	31.30	32.00	32.80	33.60	34.30	35.10	35.90	36.60	37.40	38.20	38.90	39.70	40.50	41.20
36	32.30	33.10	33.90	34.70	35.50	36.20	37.00	37.80	38.60	39.40	40.20	41.00	41.80	42.60
37	33.30	34.20	35.00	35.80	36.60	37.40	38.20	39.00	39.80	40.70	41.50	42.30	43.10	43.90
38	34.40	35.20	36.10	36.90	37.70	38.60	39.40	40.20	41.10	41.90	42.70	43.60	44.40	45.20
39	35.40	36.30	37.10	38.00	38.80	39.70	40.60	41.40	42.30	43.10	44.00	44.80	45.70	46.50
40	36.50	37.40	38.20	39.10	40.00	40.90	41.70	42.60	43.50	44.40	45.30	46.10	47.00	47.90
41	37.50	38.40	39.30	40.20	41.10	42.00	42.90	43.80	44.70	45.60	46.50	47.40	48.30	49.20
42	38.60	39.50	40.40	41.30	42.30	43.20	44.10	45.00	45.90	46.80	47.80	48.70	49.60	50.50
43	39.60	40.50	41.50	42.40	43.40	44.30	45.30	46.20	47.10	48.10	49.00	50.00	50.90	51.90
44	40.60	41.60	42.60	43.60	44.50	45.50	46.40	47.40	48.40	49.30	50.30	51.30	52.20	53.20
45	41.70	42.70	43.70	44.70	45.60	46.60	47.60	48.60	49.60	50.60	51.60	52.60	53.50	54.50

Table 2. --Price adjustment factors per thousand board feet, Scribner, by county and road distance from tract to nearest sawmill or planing mill

(In dollars)

County	Road distance to nearest sawmill or planing mill (miles)												
	1	2	3	4	5	6	7	8	9	10	15	20	25
Abbeville	2.90	3.00	3.10	3.20	3.40	3.50	3.60	3.80	3.90	4.00	4.60	5.30	5.90
Aiken	0.70	0.80	0.90	1.00	1.20	1.30	1.40	1.60	1.70	1.80	2.40	3.10	3.70
Allendale	1.80	2.00	2.10	2.20	2.40	2.50	2.60	2.70	2.90	3.00	3.60	4.20	4.90
Anderson	3.90	4.00	4.10	4.30	4.40	4.50	4.60	4.80	4.90	5.00	5.60	6.30	6.90
Bamberg	1.40	1.20	1.10	1.00	0.90	0.70	0.60	0.50	0.40	0.20	0.40	1.00	1.70
Barnwell	1.20	1.30	1.40	1.60	1.70	1.80	1.90	2.10	2.20	2.30	3.00	3.60	4.20
Beaufort	3.70	3.80	4.00	4.10	4.20	4.30	4.50	4.60	4.70	4.90	5.50	6.10	6.80
Berkeley	2.90	2.80	2.60	2.50	2.40	2.20	2.10	2.00	1.90	1.70	1.10	0.50	0.20
Calhoun	2.70	2.60	2.50	2.30	2.20	2.10	2.00	1.80	1.70	1.60	0.90	0.30	0.30
Charleston	1.00	1.10	1.30	1.40	1.50	1.60	1.80	1.90	2.00	2.20	2.80	3.40	4.00
Cherokee	4.70	4.80	5.00	5.10	5.20	5.40	5.50	5.60	5.70	5.90	6.50	7.10	7.80
Chester	3.50	3.70	3.80	3.90	4.00	4.20	4.30	4.40	4.60	4.70	5.30	5.90	6.60
Chesterfield	2.40	2.50	2.60	2.70	2.90	3.00	3.10	3.20	3.40	3.50	4.10	4.80	5.40
Clarendon	0.90	0.70	0.60	0.50	0.40	0.20	0.10	0.00	0.20	0.30	0.90	1.60	2.20
Colleton	0.20	0.30	0.40	0.50	0.70	0.80	0.90	1.00	1.20	1.30	1.90	2.60	3.20
Darlington	1.70	1.60	1.40	1.30	1.20	1.10	1.00	0.80	0.70	0.60	0.10	0.70	1.30
Dillon	1.20	1.10	0.90	0.80	0.70	0.60	0.40	0.30	0.20	0.00	0.60	1.20	1.80
Dorchester	2.60	2.40	2.30	2.20	2.00	1.90	1.80	1.70	1.50	1.40	0.80	0.10	0.50
Edgefield	0.00	0.10	0.20	0.40	0.50	0.60	0.70	0.90	1.00	1.10	1.80	2.40	3.00
Fairfield	3.20	3.30	3.50	3.60	3.70	3.80	4.00	4.10	4.20	4.40	5.00	5.60	6.20
Florence	1.90	1.70	1.60	1.50	1.40	1.20	1.10	1.00	0.80	0.70	0.10	0.50	1.20
Georgetown	1.00	0.90	0.80	0.70	0.50	0.40	0.30	0.10	0.00	0.10	0.80	1.40	2.00
Greenville	4.20	4.30	4.50	4.60	4.70	4.90	5.00	5.10	5.20	5.40	6.00	6.60	7.30
Greenwood	1.30	1.50	1.60	1.70	1.80	2.00	2.10	2.20	2.40	2.50	3.10	3.80	4.40
Hampton	1.50	1.60	1.80	1.90	2.00	2.20	2.30	2.40	2.50	2.70	3.30	3.90	4.60
Horry	2.00	2.10	2.30	2.40	2.50	2.60	2.80	2.90	3.00	3.20	3.80	4.40	5.10
Jasper	0.50	0.60	0.80	0.90	1.00	1.10	1.20	1.40	1.50	1.60	2.30	2.90	3.50
Kershaw	0.40	0.20	0.10	0.00	0.20	0.30	0.40	0.50	0.70	0.80	1.40	2.10	2.70
Lancaster	2.70	2.80	3.00	3.10	3.20	3.30	3.40	3.60	3.70	3.80	4.50	5.10	5.70
Laurens	4.00	4.20	4.30	4.40	4.60	4.70	4.80	4.90	5.10	5.20	5.80	6.40	7.10
Lee	2.50	2.60	2.80	2.90	3.00	3.20	3.30	3.40	3.50	3.70	4.30	4.90	5.60
Lexington	0.70	0.60	0.40	0.30	0.20	0.00	0.10	0.20	0.30	0.50	1.10	1.70	2.40
McCormick	0.20	0.00	0.10	0.20	0.30	0.50	0.60	0.70	0.80	1.00	1.60	2.20	2.90
Marion	3.00	3.20	3.30	3.40	3.50	3.70	3.80	3.90	4.00	4.20	4.80	5.40	6.10
Marlboro	2.40	2.20	2.10	2.00	1.90	1.70	1.60	1.50	1.40	1.20	0.60	0.00	0.70
Newberry	0.80	1.00	1.10	1.20	1.30	1.50	1.60	1.70	1.80	2.00	2.60	3.20	3.90
Oconee	0.50	0.40	0.30	0.10	0.00	0.10	0.20	0.40	0.50	0.60	1.30	1.90	2.50
Orangeburg	2.00	1.90	1.80	1.70	1.50	1.40	1.30	1.20	1.00	0.90	0.30	0.40	1.00
Pickens	2.20	2.30	2.40	2.60	2.70	2.80	2.90	3.10	3.20	3.30	4.00	4.60	5.20
Richland	1.70	1.80	1.90	2.00	2.20	2.30	2.40	2.60	2.70	2.80	3.40	4.10	4.70
Saluda	0.30	0.40	0.60	0.70	0.80	1.00	1.10	1.20	1.30	1.50	2.10	2.70	3.40
Spartanburg	4.60	4.70	4.80	4.90	5.10	5.20	5.30	5.40	5.60	5.70	6.30	7.00	7.60
Sumter	1.50	1.40	1.30	1.20	1.00	0.90	0.80	0.60	0.50	0.40	0.20	0.90	1.50
Union	3.40	3.50	3.60	3.70	3.90	4.00	4.10	4.20	4.40	4.50	5.10	5.80	6.40
Williamsburg	2.20	2.10	2.00	1.80	1.70	1.60	1.40	1.30	1.20	1.10	0.40	0.20	0.80
York	4.40	4.50	4.60	4.80	4.90	5.00	5.10	5.30	5.40	5.50	6.20	6.80	7.40

Note: Add shaded values; subtract unshaded.

Here, illustrated with an example, is how to appraise timber by this method. The cruise of the tract to be appraised shows an average volume per tree of 120 board feet. The tract is located in Newberry County, 3 miles from the nearest sawmill. How much is the timber worth when the current State average price for marked pine is $35.00 per thousand board feet?

To find out, look first in table 1, and where the 120-board-foot column intersects the $35.00 row, the basic price is $34.30. Next, look in table 2, and where the 3-mile column intersects the Newberry County row, the price adjustment factor is minus $1.10. Then, to get the value of this tract, subtract $1.10 from $34.30. Its appraised worth is $33.20 per thousand board feet.

This figure is only an estimate, of course, so the seller would not expect to receive exactly this amount. Nevertheless, he should be hesitant about accepting an offer more than five dollars below this value.

Using the Local Average Price

One item of information necessary to the above method may be difficult for an owner to obtain. This is the State average price. It is not published regularly, and the State Forester may be unable to supply the current average.

Even under these circumstances, stands can still be appraised by using an approximation method which substitutes the local price for the State average. To use it, the owner must again know the average volume per tree and the distance to the nearest mill. He must, in addition, have the same information for the tract (or group of tracts) he uses for comparison. Of course, by using local prices, he can ignore the county in which the tracts are located. Most of the arithmetic for this method has been worked out in table 3.

Table 3. --Price indicators per thousand board feet, Scribner, by road distance from tract to nearest sawmill or planing mill and average volume per tree

(In dollars)

Road distance to nearest sawmill or planing mill (Miles)	Average volume per tree (board feet)													
	40	60	80	100	120	140	160	180	200	220	240	260	280	300
1	5.10	5.80	6.50	7.20	7.80	8.50	9.20	9.90	10.60	11.30	12.00	12.70	13.40	14.10
2	4.90	5.60	6.20	6.90	7.60	8.30	9.00	9.70	10.40	11.10	11.80	12.50	13.20	13.90
3	4.70	5.30	6.00	6.70	7.40	8.10	8.80	9.50	10.20	10.90	11.60	12.30	13.00	13.70
4	4.40	5.10	5.80	6.50	7.20	7.90	8.60	9.30	10.00	10.70	11.40	12.10	12.80	13.50
5	4.20	4.90	5.60	6.30	7.00	7.70	8.40	9.10	9.80	10.50	11.20	11.90	12.60	13.20
6	4.00	4.70	5.40	6.10	6.80	7.50	8.20	8.90	9.60	10.30	11.00	11.60	12.30	13.00
7	3.80	4.50	5.20	5.90	6.60	7.30	8.00	8.70	9.40	10.10	10.70	11.40	12.10	12.80
8	3.60	4.30	5.00	5.70	6.40	7.10	7.80	8.50	9.10	9.80	10.50	11.20	11.90	12.60
9	3.40	4.10	4.80	5.50	6.20	6.90	7.50	8.20	8.90	9.60	10.30	11.00	11.70	12.40
10	3.20	3.90	4.60	5.30	5.90	6.60	7.30	8.00	8.70	9.40	10.10	10.80	11.50	12.20
15	2.10	2.80	3.50	4.20	4.90	5.60	6.30	7.00	7.70	8.40	9.10	9.70	10.40	11.10
20	1.10	1.80	2.40	3.10	3.80	4.50	5.20	5.90	6.60	7.30	8.00	8.70	9.40	10.10
25	0.00	0.70	1.40	2.10	2.80	3.50	4.20	4.90	5.60	6.20	6.90	7.60	8.30	9.00

Now let us see how a seller would use this approximation method when his stand has an average volume per marked tree of 200 board feet and is 4 miles from the nearest mill. Through inquiry, he finds that the current

average price being paid locally for marked pine sawtimber is $30.00 per thousand board feet. He finds further, that on the average these local stands have a mean volume per tree of 120 board feet, and are 5 miles from the nearest mill.

To appraise his timber, the seller first looks up in table 3 the price indicators for both his tract and the average tract. He finds that the price indicator for his is $10.00 and for the average is $7.00. Next, he takes the difference between the two price indicators, which is $3.00. Finally, he adds this difference to the local price because the indicator for his tract is greater than the one for the average. If the indicator for his tract had been smaller than that for the average, then he would have subtracted the difference between the two indicators from the local price. In the example given, the timber is worth 30 + 3, or $33.00 per thousand board feet.

COMPARING PRICES QUOTED IN VARIOUS LOG RULES

All of the above values have been based on Scribner volumes. Not all bids, of course, will necessarily be in terms of this rule. Some may be in Doyle; others in International or lumber tally, which is approximately the same. To compare offers, all must be put on the same basis. This can be done easily by using table 4 or 5, whichever is appropriate.

Table 4. --Multiplying factors for converting prices in terms of Doyle rule to a Scribner-rule basis

Average volume per tree (Board feet)	D. b. h. class with greatest volume (inches)								
	10	12	14	16	18	20	22	24	26
50	0.575	0.591	0.607	0.622	0.638	0.654	0.669	0.685	0.701
55	.583	.599	.614	.630	.646	.662	.677	.693	.709
60	.591	.607	.623	.639	.654	.670	.686	.701	.717
65	.600	.616	.631	.647	.663	.678	.694	.710	.725
70	.608	.624	.640	.655	.671	.687	.702	.718	.734
75	.616	.631	.647	.663	.679	.694	.710	.726	.741
80	.623	.639	.655	.670	.686	.702	.717	.733	.749
85	.630	.646	.662	.677	.693	.709	.724	.740	.756
90	.637	.652	.668	.684	.699	.715	.731	.746	.762
95	.642	.658	.674	.690	.705	.721	.737	.752	.768
100	.648	.664	.680	.695	.711	.727	.742	.758	.774
110	.658	.674	.690	.705	.721	.737	.752	.768	.784
120	.667	.683	.699	.714	.730	.746	.761	.777	.793
130	.675	.691	.707	.722	.738	.754	.769	.785	.801
140	.682	.698	.714	.729	.745	.761	.776	.792	.808
150	.688	.704	.720	.735	.751	.767	.783	.798	.814
160	.694	.710	.725	.741	.757	.773	.788	.804	.820
170	.699	.715	.730	.746	.762	.777	.793	.809	.824
180	.703	.719	.735	.750	.766	.782	.798	.813	.829
190	.708	.723	.739	.755	.770	.786	.802	.817	.833
200	.712	.727	.743	.759	.774	.790	.806	.821	.837
220	.718	.734	.749	.765	.781	.796	.812	.828	.844
240	.724	.739	.755	.771	.787	.802	.818	.834	.849
260	.728	.744	.760	.776	.791	.807	.823	.838	.854
280	.733	.748	.764	.780	.795	.811	.827	.843	.858
300	.737	.752	.768	.784	.799	.815	.831	.846	.862
350	.744	.760	.776	.791	.807	.823	.838	.854	.870
400	.750	.766	.781	.797	.813	.828	.844	.860	.875
450	.754	.770	.786	.801	.817	.833	.848	.864	.880
500	.758	.774	.790	.805	.821	.837	.852	.868	.884

Table 5. --Multiplying factors for converting prices in terms of International $\frac{1}{4}$-inch rule (or lumber tally) to a Scribner-rule basis

Average volume per tree (Board feet)	D. b. h. class with greatest volume (inches)								
	10	12	14	16	18	20	22	24	26
50	1.224	1.218	1.212	1.207	1.201	1.195	1.190	1.184	1.179
55	1.216	1.210	1.205	1.199	1.193	1.188	1.182	1.176	1.171
60	1.209	1.203	1.198	1.192	1.186	1.181	1.175	1.169	1.164
65	1.203	1.197	1.191	1.186	1.180	1.174	1.169	1.163	1.157
70	1.197	1.191	1.186	1.180	1.174	1.169	1.163	1.157	1.152
75	1.192	1.186	1.181	1.175	1.169	1.164	1.158	1.152	1.147
80	1.187	1.181	1.176	1.170	1.165	1.159	1.153	1.148	1.142
85	1.183	1.177	1.172	1.166	1.160	1.155	1.149	1.143	1.138
90	1.179	1.173	1.168	1.162	1.157	1.151	1.145	1.140	1.134
95	1.176	1.170	1.164	1.159	1.153	1.147	1.142	1.136	1.130
100	1.172	1.167	1.161	1.155	1.150	1.144	1.138	1.133	1.127
110	1.167	1.161	1.155	1.150	1.144	1.138	1.133	1.127	1.122
120	1.162	1.156	1.150	1.145	1.139	1.134	1.128	1.122	1.117
130	1.158	1.152	1.146	1.141	1.135	1.129	1.124	1.118	1.112
140	1.154	1.148	1.143	1.137	1.131	1.126	1.120	1.114	1.109
150	1.151	1.145	1.139	1.134	1.128	1.122	1.117	1.111	1.105
160	1.148	1.142	1.136	1.131	1.125	1.120	1.114	1.108	1.103
170	1.145	1.140	1.134	1.128	1.123	1.117	1.111	1.106	1.100
180	1.143	1.137	1.132	1.126	1.120	1.115	1.109	1.103	1.098
190	1.141	1.135	1.130	1.124	1.118	1.113	1.107	1.101	1.096
200	1.139	1.133	1.128	1.122	1.116	1.111	1.105	1.099	1.094
220	1.136	1.130	1.124	1.119	1.113	1.107	1.102	1.096	1.090
240	1.133	1.127	1.122	1.116	1.110	1.105	1.099	1.093	1.088
260	1.130	1.125	1.119	1.114	1.108	1.102	1.097	1.091	1.085
280	1.128	1.123	1.117	1.111	1.106	1.100	1.095	1.089	1.083
300	1.127	1.121	1.115	1.110	1.104	1.098	1.093	1.087	1.081
350	1.123	1.117	1.112	1.106	1.100	1.095	1.089	1.083	1.078
400	1.120	1.115	1.109	1.103	1.098	1.092	1.086	1.081	1.075
450	1.118	1.112	1.107	1.101	1.096	1.090	1.084	1.079	1.073
500	1.116	1.111	1.105	1.099	1.094	1.088	1.082	1.077	1.071

Prices quoted in Doyle rule can be converted to Scribner by using table 4. The same thing can be done with prices given in terms of International $\frac{1}{4}$-inch rule or lumber tally by using table 5. All the seller needs to know is the average volume per tree and the d. b. h. class which contains the greatest volume, for his marked trees. For example, if the average volume per tree is 110 board feet and the d. b. h. class with the greatest volume is 14 inches, the Doyle-to-Scribner converting factor is 0.690 and the International- or lumber tally-to-Scribner converting factor is 1.155. For this stand, then, an offer of $43.50 per thousand board feet, in Doyle, would be equivalent to $30.00 per thousand board feet, Scribner ($43.50 x 0.690 = $30.00); and a quotation of $26.00 per thousand board feet, in International (or lumber tally), would also be equal to $30.00 per thousand board feet, Scribner ($26.00 x 1.155 = $30.00).

DETERMINATION OF THE PRICE ESTIMATING EQUATION

The appraisal method just described is a practical way of applying the results of a study which was designed to explain tract-to-tract variations in timber prices. This is the third in a series of studies conducted by this Station with the objective of explaining stumpage price variation among pine stands. The first of these investigations, conducted in Georgia by Todd and Zirkle,[1/] attempted to identify both quantitative and qualitative factors affecting price. The second, an exploratory study by Cruikshank and Anderson,[2/] endeavored to explain price differences among sales of pine sawtimber in South Carolina in terms of measurable stand characteristics. The present study is similar to the second, but many more variables have been tested.

The Sample of Sales

The data used in this investigation were taken from service foresters' reports to the South Carolina State Commission of Forestry. Service foresters, operating under the Cooperative Forest Management Act of 1950, mark privately owned stands for cutting, among the other functions they perform. For a portion of the marked tracts, they reported the price paid, the date of sale, the number of bids received, the location of the tract, and the tally of the trees marked. From these records, reports for 93 sales were selected for analysis.

Although originally made for administrative rather than research purposes, these reports were particularly well suited to this study. First, they included sales made throughout the State. Second, the prices paid were for tracts that had been marked and cruised by a qualified timber marker, so each seller knew the volume he was offering for sale. And in 85 percent of the cases the seller received more than one bid. Finally, the prices could be readily analyzed because stand characteristics and other factors that might influence price were known for each sale.

To relate stumpage price to each of its determinants, it is desirable to have all other factors held constant. For this reason, the ideal sales to analyze would appear to be those that had all taken place at the same time, i.e., cross-section data. But, unfortunately, results could not explain price differences among tracts at any other point in time when the price level might be either lower or higher. More suitable data for a price study intended as the basis for a timber appraisal method should be those from sales made during an interval of several years. Differences in price levels at the time each sale took place can be eliminated by expressing each individual price as a deviation from the current average price at the time the

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1/ Todd, A. S., Jr., and Zirkle, J. J., Jr. Marketing farm timber in Monroe County, Georgia. U. S. Forest Serv. Southeast. Forest Expt. Sta. Paper 3, 33 pp. 1949.

2/ Cruikshank, J. W., and Anderson, W. C. Pine sawtimber stumpage prices in South C[illegible] 1948-1954. U. S. Forest Serv. Southeast. Forest Expt. Sta. Paper 57, 14 pp. 1955.

sale was made. When this is done, differences in the prices paid for various tracts can be explained in the same manner as with cross-section data. Furthermore, in instances where the relationship of stumpage price to any of its determinants is influenced by the price level, the current average price can be included as an independent variable in the estimating equation. Therefore, for this study, sales were selected that had occurred between 1946 and 1956.

During this 10-year period, the general level of pine sawtimber prices tended upward, but also fluctuated widely around this trend (fig. 1). Before attempting to remove the influence of both the long-term and short-term movements, tests were made to detect differences in the general price pattern among the seven forest districts of the State. There were none, so it was reasonable to adjust all individual prices to one base price level. To do this, first, 354 prices were plotted by year and month of sale, and then a line was drawn which passed through the annual average prices and followed the ups and downs of the monthly averages. This line represented the general price level in the State throughout this interval. Next, each of the prices paid in the 93 sales used in the analysis was measured as a difference between the price actually paid and the current average price for the State in the month the sale was made. Finally, these differences were added algebraically to the grand average price for the entire period, thereby getting rid of negative numbers. Because none of the stand variables or other factors likely to be related to price showed any trend over the period, these prices appeared to satisfactorily simulate those collected at one point in time and were the ones used in the analysis.

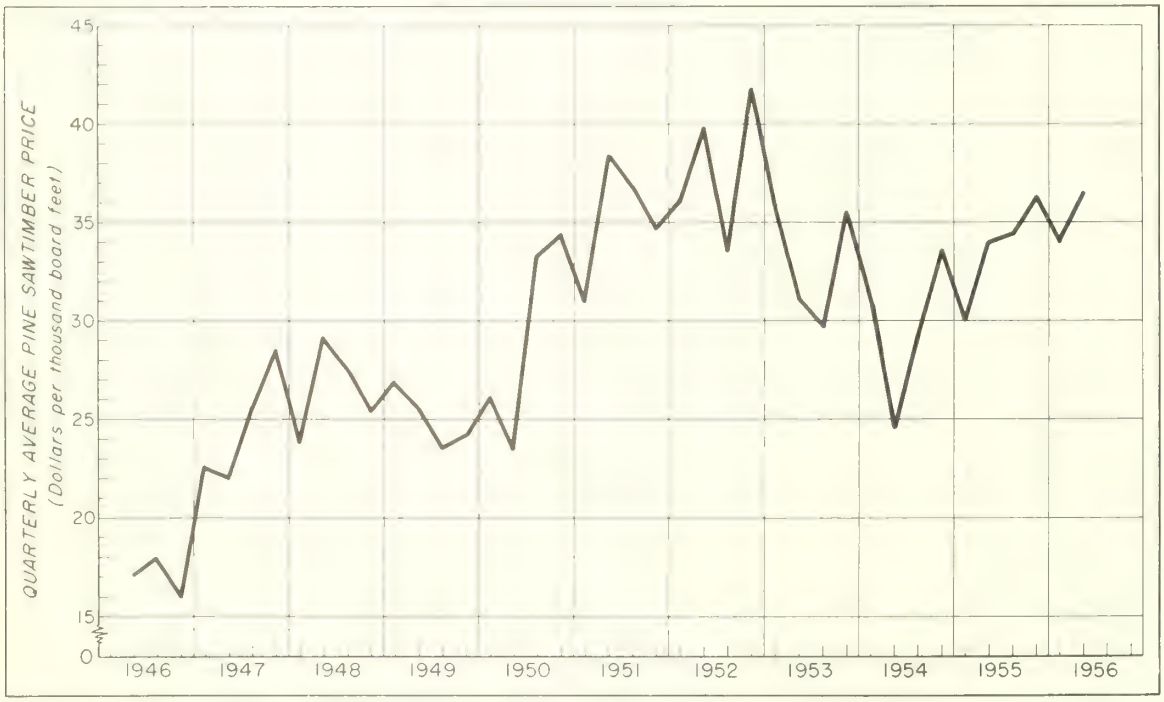

Figure 1. --Stumpage prices moved upward but fluctuated widely about the trend. Within years, prices tended to be highest in the fall.

The Potential Price Determinants

In appraisals made according to standard procedures, stumpage price is treated as a residual value. It is computed by deducting production costs and allowances for profit and risk from the selling price for lumber. If this approach is rational, then the factors that influence the price paid for a particular lot of standing trees must operate indirectly through their effect on the value of lumber that can be produced, the cost of producing and delivering it to market, and the amount allowed for the operator's profit and risk.

Although the price received for any delivery of lumber is determined almost entirely by the level of average lumber prices, more or less may be paid for the lumber from a particular tract depending upon the size and quality of the boards that are sawed. Logging and milling costs are affected by the size of trees, their spacing, and the character of the area they occupy. Lumber and log transportation costs vary with distance from the tract to the mill and the type of roads over which the loads are hauled. The degree of competition among bidders limits the allowance for profit and risk the buyer can claim. The effects of these general factors are reflected in the stumpage price.

Of the numerous measures of possible price determinants, 23 could be tested for their relationship to price with the data available. Specifically, these were:

Number of acres in sale area
Total volume marked and sold
Average volume marked per acre
Proportion of volume in trees over 19 inches d. b. h.
Proportion of volume in trees over 15 inches d. b. h.
Average volume per marked tree
Average number of trees marked per acre
Average d. b. h. of marked trees
Average merchantable height of marked trees
Ratio of d. b. h. to merchantable height
Stand quality (a qualitative estimate)
Average form class of marked trees
Distance from tract to nearest all-weather road
Distance by road from tract to nearest stationary sawmill or planing mill
Number of bids received
Total area of forest on timber seller's land
Proportion of seller's land in forest
Number of sawmills in county
Annual lumber production in county
Annual softwood lumber production in county
Annual softwood lumber production per million board feet of softwood sawtimber inventory in county
Average annual income per farm in county
Geographic location

The Factors Related to Price

Regression analysis showed that of the variables considered, only four were significant. These were: (1) Volume per tree, (2) distance to mill, (3) number of bids, and (4) geographic location. Together, these four variables explained 58 percent of the price variance.

The relationship between price and average size of marked trees was positive. The average volume per tree for all tracts used in computing this equation was 154 board feet. The tract containing the smallest trees had an average of only 52 board feet; the one with the largest trees had an average of 476 board feet. Buyers were willing to pay a higher price per thousand board feet for stands of large trees because (1) they could harvest and convert them to lumber more cheaply, and (2) large trees yield a higher proportion of No. 1 common and better lumber.

The relationship of price to tree size depended on the level of average timber prices. At high price levels, buyers paid a greater premium for large trees than they did at low price levels (fig. 2). For example, when the average price was down to $20.00, only $2.20 more per thousand was paid for a stand with an average volume of 300 board feet per tree than for one with 200 board feet per tree. But when the price level went up to $35.00, the price difference between stands of these sizes was $3.80 per thousand board feet.

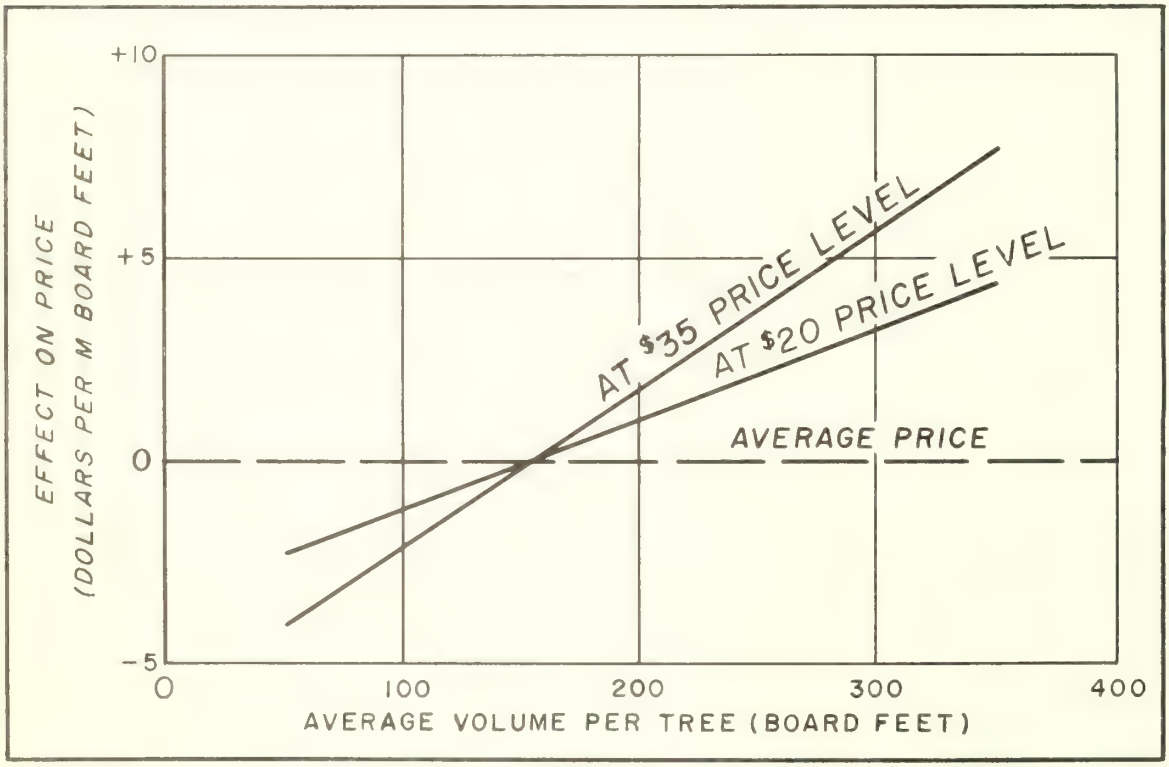

Figure 2. --Higher prices were paid for sawtimber stands with large trees, especially when the State average price was high.

Either the logs or the rough, green lumber cut at the tract had to be hauled at least as far as the nearest stationary sawmill or planing mill. The shortest distance for any sale was 1 mile, the longest was 25 miles, and the average was 6 miles. In all sales, of course, the mill nearest the tract had a competitive advantage. Nearness to mill may also be a rough indicator of the number of mills in the area, which would affect the competition for stumpage. There was a negative relationship between price and the distance to this mill (fig. 3). Each additional mile from the nearest mill reduced stumpage price by an average of 13 cents per thousand board feet.

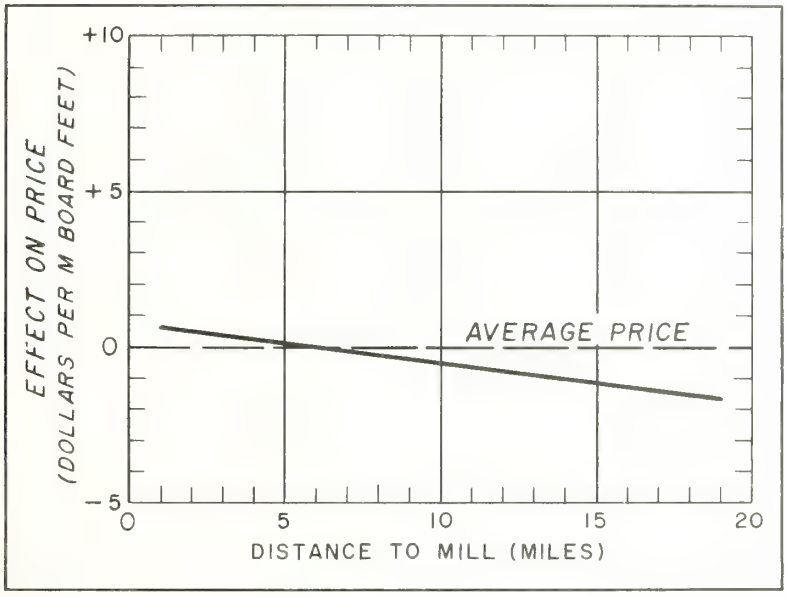

Figure 3. --Sawtimber prices declined with increases in the hauling distance to the nearest stationary sawmill or planing mill.

The number of bids an owner received indicated the amount of competition among interested buyers. Of course, the more intensive this competition, the higher the price the seller was likely to get. The number of bids received in individual sales ranged from 1 to 11, and the average was 3. Up to three bids, each additional bid increased the sawtimber price by $1.25 per thousand board feet (fig. 4). But beyond this number, additional bids apparently had a negligible effect on the price.

After both the effect of average volume per tree and distance to mill had been removed, there still remained a residual variability of price associated with geographic location. Prices tended to increase from the northwest corner of the State toward the coast (fig. 5). However, tidewater counties had lower average prices than those only a short distance inland. To measure the effect of geographic location, counties were arrayed on the basis of average prices calculated from 354 sales, and assigned ranks from lowest to highest. There was an average difference of 17 cents between counties with adjacent ranks, or $7.60 between the counties with the highest and lowest ranking. Consequently, an equation incorporating county rank is a better estimator than one without it.

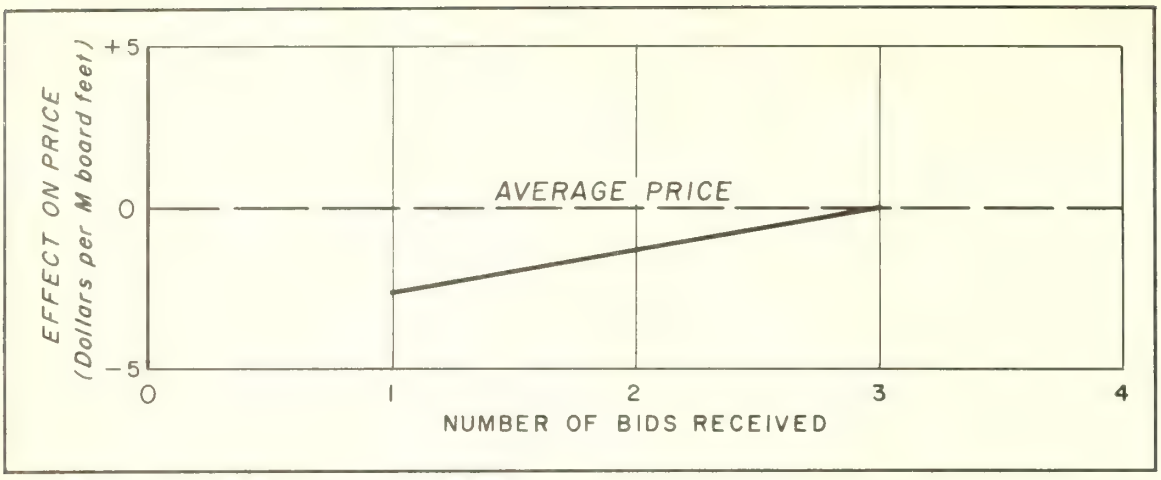

Figure 4. --Prices paid for sawtimber stands were lowest where competition for the timber, as reflected in the number of bids received, was least.

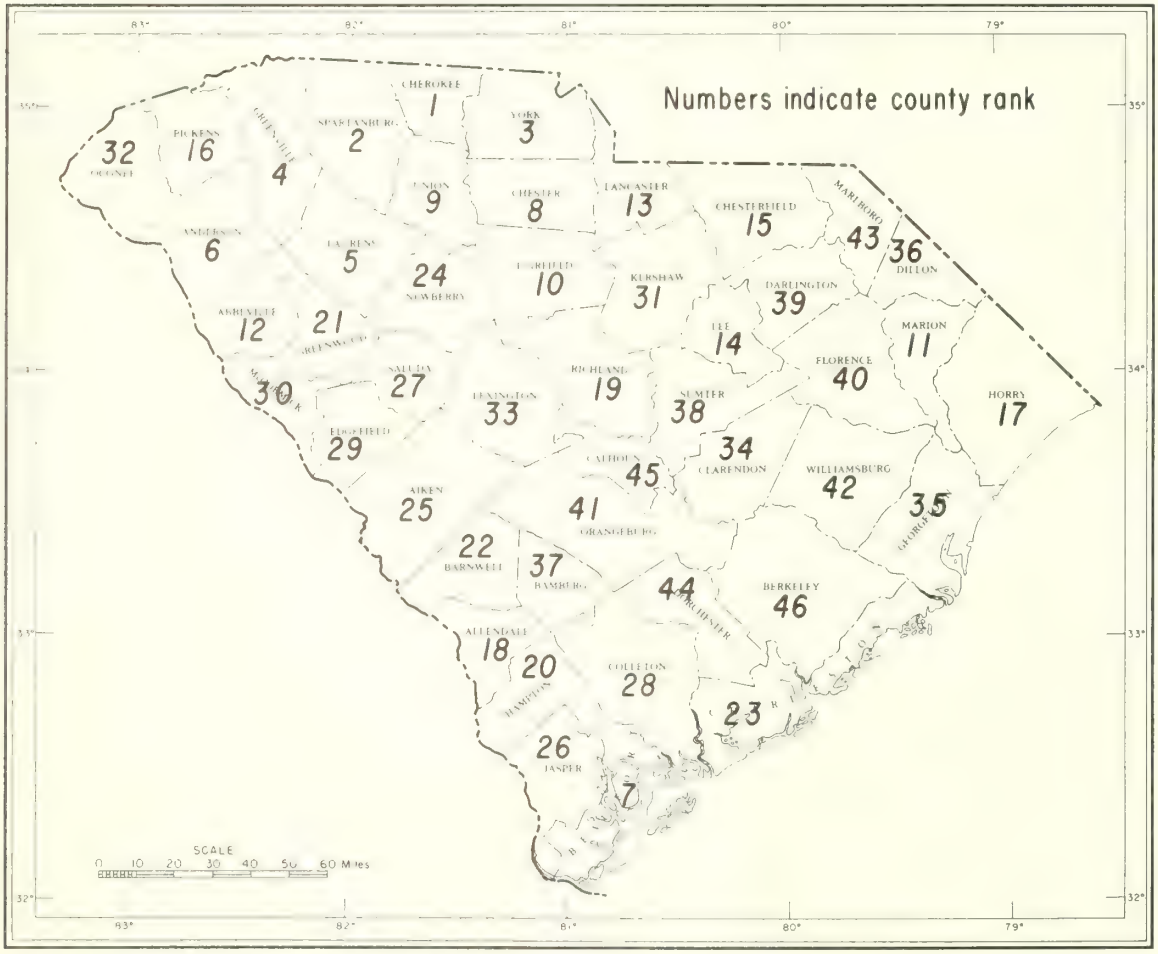

Figure 5. --When counties were ranked by average price from lowest to highest, county rank tended to increase from the northwestern part of the State toward the coast, but was lower along the coast.

The relationship of each of these four significant variables to price is shown in the following estimating equations:

$$y = 0.001096x_1 - 0.126939x_2 + 1.257878x_3 + 0.168988x_4$$

where the variables, expressed as deviations from their respective means are:

y = estimated pine sawtimber price in dollars per thousand board feet

x_1 = State average price in dollars per thousand board feet times the average volume per marked tree in board feet

x_2 = road distance to the nearest stationary sawmill or planing mill in miles

x_3 = number of bids received

x_4 = rank of county when counties were arrayed in order from those with the lowest to those with the highest average price

For this equation, the standard error for the estimated price of an individual tract was $4.60 per thousand board feet (14 percent at the mean).

To simplify application of this equation, the values in tables 1 and 2 were calculated. To illustrate how table 1 was obtained, consider a tract with an average volume per tree of 100 board feet sold at a time when the current State average price was $30.00 per thousand board feet. The first step in computing the "basic price" shown in this cell of the table was to multiply the average volume per tree by the current State average price, 100 (30) = 3000. Second, the difference was found between 3000 and the mean of the equivalent values for all tracts used in the study, 3000 - 4813 = -1813. Third, this difference was multiplied by the regression coefficient for x_1 shown in the equation, 0.001096 (-1813) = -1.99. Finally, this result was added algebraically to the current State average price, 30.00 - 1.99 = 28.01. This gave the basic price, $28.00, when rounded to the nearest ten cents.

For a tract located in Richland County 4 miles from the nearest sawmill, the factor shown in table 2 was obtained as follows: First, the distance to the mill was expressed as the difference between the actual distance of this tract from the nearest mill and the mean distance of all tracts from the mill nearest them, 4.0 - 6.1 = -2.1. When this value was multiplied by the regression coefficient for x_2, the effect of distance on price was -0.126939 (-2.1) = 0.27. Next, the effect of geographic location on price was found by taking the difference between the rank of Richland County, nineteenth, and the mean county rank of all tracts, 19.0 - 29.5 = -10.5, and multiplying this difference by the coefficient for x_4, 0.168988 (-10.5) = -1.77. Then the adjustment of the estimated price to a 3-bid basis was also included in this factor. This was done by subtracting the mean number of bids, 3.44, from 3 and multiplying the result by the coefficient for x_3, 1.257878 (-0.44) = -0.55. Lastly, these three price effects were summed algebraically, 0.27 - 1.77 - 0.55 = -2.05, and the answer was rounded to the nearest ten cents, i.e., - $2.00. This is the "price adjustment factor" shown for this cell in table 2.

The values in table 3 were worked out in a similar fashion to those in tables 1 and 2 except, of course, they were based on an estimating equation that excluded geographic location. The regression coefficients of the variables retained in this equation were:

$$y = 0.001315x_1 - 0.221477x_2 + 1.497471x_3$$

where the variables are identified by the same symbols used in the first equation.

One variable, which previous studies found to influence stumpage price, failed to show significance in this study. It was volume per acre. This different result appears to be primarily due to the number of observations involved. In the earlier study of South Carolina pine stumpage prices, 3/ based on 380 sales, volume per acre was significant at the 5-percent level. This was no longer true, however, when the number of sales was reduced to only 93. Apparently the association between this factor and price was so slight it could be detected only with a large sample.

ADDITIONAL FACTORS THAT MAY BE RELATED TO PRICE

In addition to those considered in this study, there may be other factors that significantly influence stumpage price but could not be tested because they had not been measured. Three outstanding factors left out of the analysis for this reason were: (1) Accessibility to the tract, (2) difficulty of the logging chance, and (3) quality of the stand.

Accessibility and difficulty of the logging chance are generally related. Over much of the State, most tracts are near all-weather roads and the topography does not hamper logging. But those areas in the mountains and along the coast where logging is most difficult are often the least accessible. The difficulty of reaching and working coastal stands may be one reason why stumpage prices are lower there.

Stand quality was considered in this analysis only in a rough way. It was measured in part by tree size, and in part by the ratio of average tree height to average d. b. h. A subjective estimate of stand quality was also tested. But there was no measure of knottiness or other degrading factors. Whether or not quality affects stumpage price in this State is a matter of conjecture. In an area such as this where the portable mills cut and sell rough, green lumber and many of the larger mills use gang saws to increase output, it is possible that stand quality is of minor importance.

3/ See footnote 2.

CONCLUSIONS

This study provides a method for translating the general average price into the average price a specific tract would bring. It demonstrates that in spite of the great variability in the characteristics of pine sawtimber in South Carolina, well over half of the price variation among tracts can be explained with a few measurable variables.

Of course, the analysis does not provide a complete explanation of price behavior. But in our daily lives, we accept many imprecise explanations because of their usefulness. And by reducing the number of factors represented in the complex process of setting a price on stumpage, we can express useful information about this process which otherwise would have to be accepted as random. As better ways are found for measuring potential price determinants, the explanation of stumpage prices may be further improved. In this way, we can provide better market information to timber sellers than has been available in the past.

Agriculture - Asheville

tion Paper No. 123

AUG 3 - 1961

June 1961

Yield of Unmanaged Slash Pine Stands in South Florida

by

O. Gordon Langdon

ACKNOWLEDGMENTS

The author gratefully acknowledges the assistance of the following cooperators and individuals: Robert E. Byrd, Leonard Greenwood, Harry Orwig, and Keith Pippin of the Atlantic Land and Improvement Company; Randall Specht, Virgil Davis, and Maynard Leetun of the American Agricultural Chemical Company; W. Kay Conard, Kenneth Arnold, L. B. Burnette, and Herman Spooner of the Collier Company; John Rogers of the Lee Tidewater Cypress Company; Robert Titus, George Reinert, Norman Lain, and Robert Kornegay of the Florida Forest Service; Rees Snedaker of Rayonier, Inc.; and Ellery A. Foster, consulting forester.

U.S. Department of Agriculture
Forest Service
Southeastern Forest Experiment Station
Asheville, North Carolina

COVER PHOTO

A 60-year unmanaged stand of South Florida slash pine.

Southeastern Forest Experiment Station
P. O. Box 2570, Asheville, N. C.

ERRATA

Station Paper 123, "Yield of Unmanaged Slash Pine Stands in South Florida" by O. Gordon Langdon.

Page 7, line 4, Equation 2--Delete "Log," to read:

$$\hat{Y}_4 = 6.50085 - 0.66896\left(\frac{100}{A}\right) + 1.02364\left(\frac{SI}{10}\right) - 1.13411\left(\frac{SDI}{100}\right) \qquad \text{(Equation 2)}$$

Line 6 should read:

where $\hat{Y}_4$ = average stand diameter in inches at breast height.

Yield of Unmanaged Slash Pine Stands in South Florida

by

O. Gordon Langdon

Predictions of future timber yields are necessary for formulating management plans and for comparing timber growing with alternative land uses. One useful tool for making these predictions is a set of yield tables.

Timber growth and yield information for south Florida has been lacking; consequently, the forest productive potential has been largely an unknown quantity. Owners of the 7.9 million acres of commercial forest land in south Florida were necessarily forced to base management decisions of land use on very scanty forestry information. As young natural stands have become established and as general interest in forestry and tree planting has developed, the demand for growth and yield data has increased. This paper is published to fill this critical need until more complete data are collected for both managed and unmanaged stands.

STUDY PROCEDURE

The initial measurements of 90 permanent plots in a slash pine growth study provided the basic data used in compiling the tables and graphs contained in this report. These plots were established in stands varying in age from 8 to 61 years, in site index (based on age 25) from 30 to 77, and in stand density index from 26 to 321.

Field Work

Circular, $\frac{1}{4}$-acre plots were used with a 33-foot border strip having the same stand density as the plot itself. Pure, even-aged stands were required with not more than 25 percent of the stand composed of other species. Trees had to be evenly distributed before an area was selected for a plot; stands with appreciable clustering were not admitted. Stands could not show evidence of severe disease or insect attack or cutting within the past 5 years.

Measurements on the plot included a diameter tally and a crown classification of all trees. Height and age were obtained from sample trees selected from each diameter class. A height-diameter curve was drawn for each plot and used to determine the average tree height by diameter classes.

Study Areas

Plots were established in Collier, Hendry, Lee, Polk, Citrus, Hernando, Sumter, and Pasco Counties, Florida. Cooperators contributed land for the plots, help in locating and establishing the plots, and supervision in the cutting.

The topography of the study area is for the most part very flat, surface drainage is poor, and ground water levels are usually within 4 feet of the soil surface. Soils on the plots were classified in the following series: Broward, Charlotte, Felda, Immokalee, Keri, Leon, Ona, Pompano, and Sunniland; several others could not be classified.

Plot Summaries

Average plot age and total height were based on a sample of dominant and codominant trees. These averages were in turn used to determine site index from the curves derived as described in a later section. Measures of stand density, such as number of trees, basal area, and Reineke's (3) stand density index, were calculated.[1/] Reineke's curves were used in this study (fig. 1), and the relation of stand density index to average stand diameter, basal area, and number of trees per acre is shown in table 1.[2/] Average stand diameter was determined from the tree of average basal area.

Plot volumes in merchantable cubic feet and board feet ($\frac{1}{4}$-inch International Rule) per acre were calculated by 2-inch diameter classes for threshold diameters of 4.5 and 9.0 inches d.b.h. The volume tables for South Florida slash pine (1) were used to determine tree volumes (table 2).

Statistical Analysis

Multiple regression methods were used in the analysis of the plot data to determine the relation of the volume yield to stand age, site index, stand density index, and their interactions. The Schumacher (4) equation form for these yields was:

$$\text{Log } Y = b_0 + b_1 X_1 + b_2 X_2 + b_3 X_3 + b_4 X_4 + b_5 X_5 + b_6 X_6$$

where, Log Y = Logarithm of yield in merchantable cubic feet or board feet

$X_1 = \dfrac{1}{\text{Average stand age (A)}}$

X_2 = Site index at age 25 (SI)

X_3 = Stand density index (SDI)

$X_4 = X_1 X_2$

$X_5 = X_1 X_3$

$X_6 = X_2 X_3$

b with subscripts = coefficients derived from the data

1/ Reineke's stand density index was used as a measure of stand density rather than basal area because a statistical test showed it to account for more variation. Other measures of stand density not tested might have served as well as the one chosen.

2/ All tables referred to in the text appear in the Appendix.

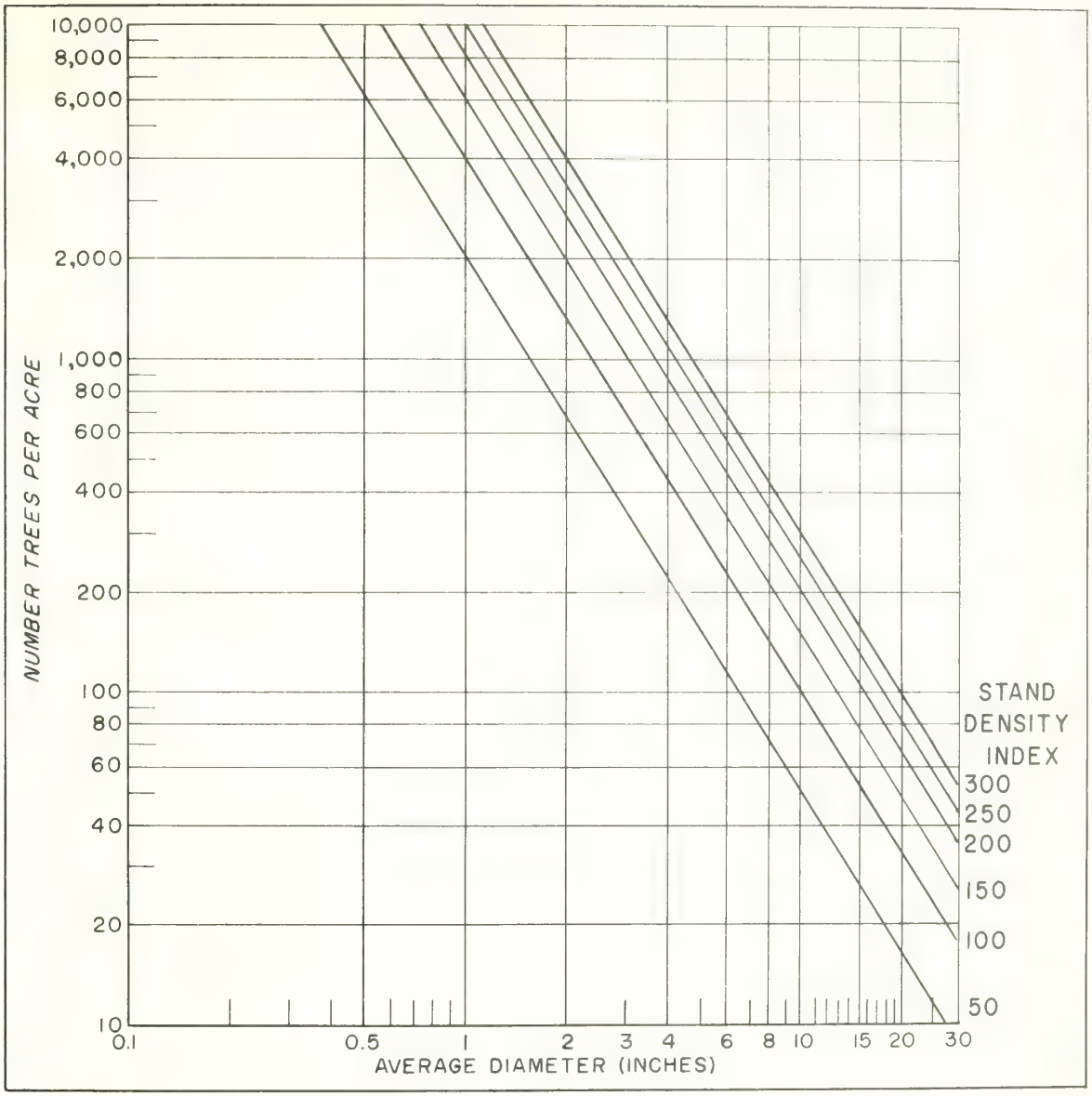

Figure 1.--Reineke's stand density index curves.

All possible combinations (63 in all) of regressions with the variables were not considered in this analysis. The selection and order of fitting the variables was determined by the contribution of the variables to the residual sum of squares. The variable that accounted for the most variation in a given step of the analysis was removed in that step. The variables in the four equations presented in this paper are listed in a descending order of fit. Curvilinearity was tested by plotting the residuals (Log Y - Log $\hat{Y}$) over each of the variables.

RELATED STUDIES

Site Index Curves

New site index curves for South Florida slash pine were constructed from data collected on the growth plots (2). This was necessary because existing slash pine site index curves, based either on data from the entire range of both varieties of slash pine or from only a portion of the range of the northern variety of slash, differed significantly from the new curves.

The linear regression computed was:

$$\text{Logarithm of total height} = 1.881 - 4.628 \left(\frac{1}{\text{Age}}\right)$$

and expressed in terms of site index at age 25 it became

$$\text{Logarithm of site index} = \text{Logarithm of total height} + 4.628 \left(\frac{1}{\text{Age}} - \frac{1}{25}\right)$$

The set of site index curves in figure 2 was derived from this equation.

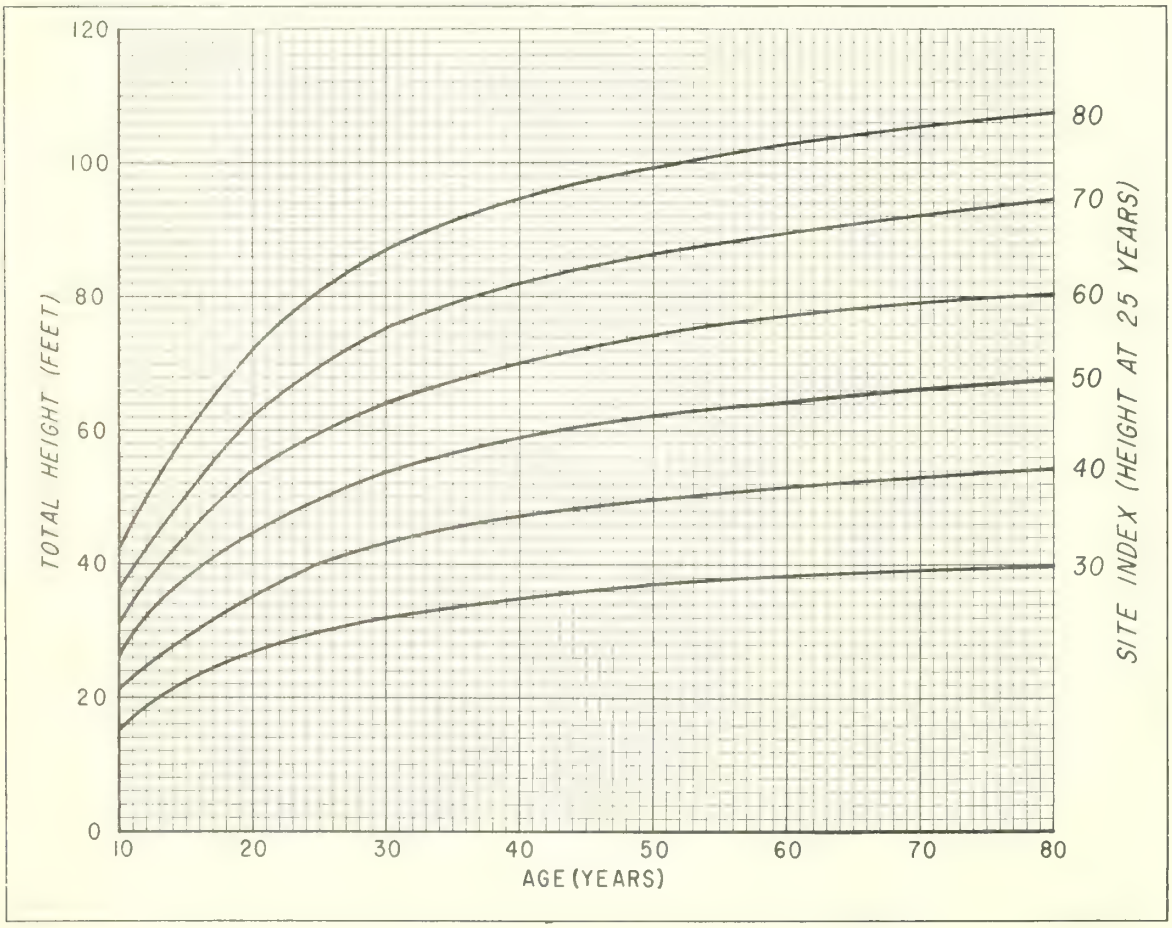

Figure 2.--Site index curves at index age of 25 years for slash pine in south Florida.

Independent height-age data collected by the Forest Survey from plots in 22 southern counties of south Florida were tested against the data from this study. The regression coefficients from the two sets of data were not significantly different.

Volume Tables

New volume tables (tables 2 and 3) were compiled for use in this yield study (1) because tables based on South Florida slash pine data were not available and other existing volume tables were inaccurate.

The volume tables were developed from measurements of 51 pulpwood-size trees (4.5 to 10.9 inches d.b.h.) and 80 trees of saw-log size (9.0 to 22.4 inches d.b.h.). The minimum top diameter limits were 3.5 inches inside bark for pulpwood and 7.5 inches inside bark for saw logs. The minimum size for a saw-log tree was 9.0 inches d.b.h. with one 16-foot log. The trees measured were from a sample not associated with the yield plots and were selected to cover the range of site conditions, form, and tree sizes found in south Florida.

The volume tables were prepared by regression methods using the general formula: $V = b_o + b_1 D^2 H$, where V = tree volume, D = diameter breast height, and H = total tree height.

STUDY RESULTS

Yields were computed for: (1) Total merchantable cubic-foot volume (including both pulpwood and/or saw logs); (2) saw log cubic-foot volume; and (3) saw log board-foot volume by the $\frac{1}{4}$-inch International Rule. A fourth analysis estimated average stand diameter from stand age, site index, and stand density index.

Yield and Growth

The prediction equation for total merchantable cubic-foot yield was:

$$\text{Log } \hat{Y}_1 = 3.70240 - 37.861 \left(\frac{1}{A}\right) + 0.38828 \left(\frac{SI}{A}\right) + 0.03337 \left(\frac{SDI}{A}\right) \qquad \text{(Equation 1)}$$

where $\text{Log } \hat{Y}_1$ = logarithm of yield in cubic feet outside bark for trees 4.5 inches d.b.h. and larger to a minimum top diameter limit of 3.5 inches inside bark.

The variables in this equation were all highly significant, and together accounted for 90.5 percent of the variation about the mean. The other variables tested did not significantly improve this yield estimate.

The regression showed that total merchantable yield varied with increasing age and with the ratios of site index to age and stand density index to age. These yields were tabulated for age, site index, and stand density index classes (table 4).

Total merchantable mean annual growth for merchantable cubic-foot volumes was computed from the yield prediction equation (table 5). Mean annual growth generally culminates later on poorer sites and for any one given site later in the lower stand densities.

Cubic- and board-foot equations were developed to determine the yield of the saw-log portion of the stand. These equations showed that yields of saw-log material increase with decreasing stand density. This apparent paradox, although reasonable for stands with an average diameter below the 9-inch threshold, is not compatible with the growth of stands whose average diameters are well above this threshold. Therefore, these equations are not presented, but instead two tables (tables 6 and 7) are included using the average stocking encountered in this study (stand density index class 200). Table 6 shows the proportion of the merchantable yield in saw-log sizes, and table 7 shows the board-foot yields.

The board-foot:cubic-foot ratio of the saw-log volume was calculated (fig. 3), and is useful in comparing sawtimber and pulpwood stumpage values.

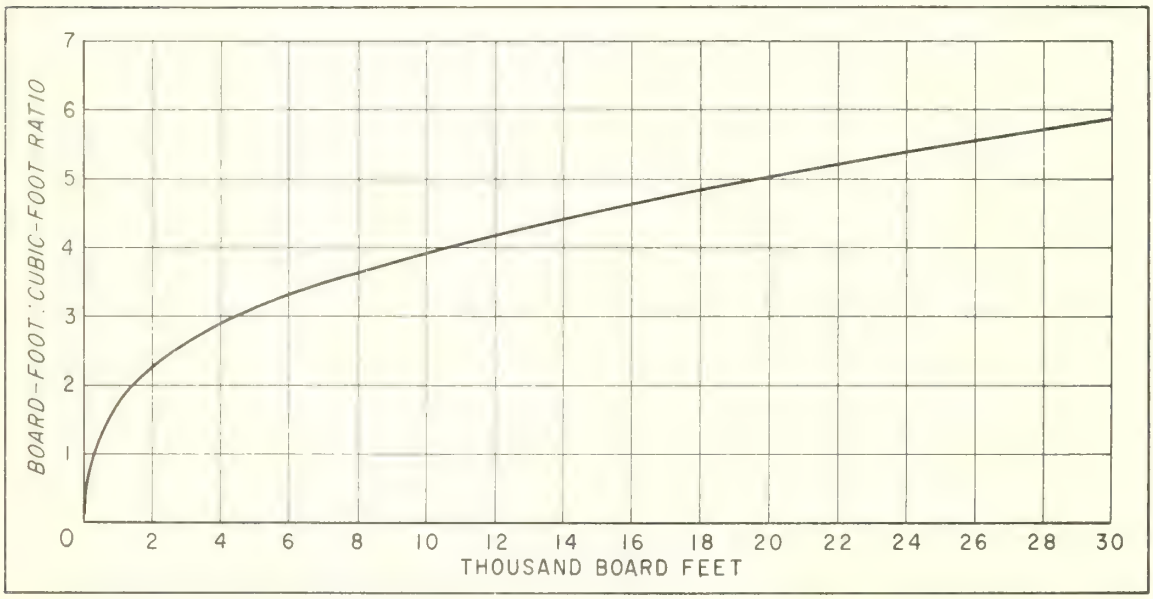

Figure 3.--Freehand curve showing board-foot:cubic-foot ratio by stand volume in board feet.

Average Stand Diameter

The effects of age, site index, and stand density index on average stand diameter for unmanaged slash pine stands were examined, and the following regression expressing this relationship was derived:

$$\text{Log } \hat{Y}_4 = 6.50085 - 0.66896 \left(\frac{100}{A}\right) + 1.02364 \left(\frac{SI}{10}\right) - 1.13411 \left(\frac{SDI}{100}\right) \qquad \text{(Equation 2)}$$

where Log $\hat{Y}_4$ = average stand diameter in inches at breast height.

All of these variables were highly significant and together accounted for 72.6 percent of the total variation about the mean. Table 8 shows the tabulated results that were computed from the above equation.

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Appendix

USE OF TABLES AND FIGURES

The tables and figures contained in this paper may be used to estimate stand volume, size, and condition. For example, a 40-year-old stand on a site index of 50 with a stand density index of 200 would, according to the estimates contained in the cited tables and figures, have the following characteristics on a per-acre basis:

Characteristics	Table
Total merchantable cubic-foot volume--2560 cubic feet	4
Mean annual growth--64 cubic feet at 40 years of age	5
Proportion of merchantable stand volume in saw-log sizes--40 percent, or 1024 cubic feet in saw-log volume	6
Board-foot volume--2820 board feet	7
Average stand diameter--7.7 inches d.b.h.	8
Number of trees--310	1
Basal area--99 square feet	1
	Figure
Average height of dominant and codominant--59 feet	2
Board-foot:cubic-foot ratio--2.5	3

Table 1. --Relation of stand density index to average stand diameter, trees per acre, and basal area per acre

Stand density index	Average stand d. b. h.	Trees per acre	Basal area per acre
	Inches	Number	Square feet
100	5	305	42
	6	230	45
	7	180	48
	8	145	51
	9	120	53
	10	100	55
150	5	450	61
	6	340	67
	7	265	71
	8	214	75
	9	178	79
	10	150	82
200	5	600	82
	6	450	88
	7	360	96
	8	290	101
	9	240	106
	10	200	109
250	5	760	104
	6	570	112
	7	445	119
	8	360	126
	9	295	130
	10	250	136
300	5	900	123
	6	680	133
	7	525	140
	8	430	150
	9	355	157
	10	300	164

Table 2. --Merchantable cubic-foot volume, outside bark, for South Florida slash pine, by diameter and total tree height 1/

D. b. h. (Inches)	Total height (feet)												
	30	35	40	45	50	55	60	65	70	75	80	85	90
	Cubic feet												
5	1.69	2.05	2.40	2.76	3.11	3.47	3.82	4.17	4.53				
6	2.63	3.14	3.65	4.16	4.67	5.18	5.69	6.20	6.72				
7	3.73	4.43	5.13	5.82	6.52	7.21	7.91	8.61	9.30				
8	5.01	5.92	6.83	7.74	8.65	9.56	10.46	11.37	12.28				
9	6.46	7.61	8.76	9.91	11.06	12.21	13.36	14.51	15.66	16.81	17.96	19.11	20.26
10	8.08	9.50	10.92	12.34	13.76	15.18	16.60	18.02	19.44	20.86	22.28	23.70	25.12
11			13.59	15.18	16.78	18.38	19.98	21.57	23.17	24.77	26.37	27.96	29.56
12			16.02	17.92	19.82	21.72	23.62	25.52	27.42	29.32	31.22	33.12	35.02
13			18.66	20.89	23.12	25.35	27.58	29.81	32.04	34.27	36.50	38.73	40.96
14			21.51	24.09	26.68	29.27	31.86	34.44	37.03	39.62	42.21	44.79	47.38
15			24.57	27.54	30.51	33.48	36.45	39.42	42.39	45.36	48.33	51.30	54.27
16				31.22	34.60	37.98	41.36	44.74	48.12	51.50	54.88	58.26	61.64
17				35.14	38.96	42.77	46.59	50.40	54.22	58.03	61.85	65.66	69.48
18				39.30	43.58	47.85	52.13	56.41	60.69	64.96	69.24	73.52	77.79
19				43.70	48.46	53.23	57.99	62.76	67.52	72.29	77.05	81.82	86.58
20					53.61	58.89	64.17	69.45	74.73	80.01	85.29	90.57	95.85
21					59.02	64.84	70.66	76.49	82.31	88.13	93.95	99.77	105.59
22					64.70	71.09	77.48	83.86	90.25	96.64	103.03	109.42	115.81

1/ Tabular values for the 5- to 10-inch d. b. h. classes from equation:

$V = 0.00284\ D^2\ H - 0.44$; standard error of mean = ± 0.11 cu. ft. or ± 1.19 percent; Coefficient of determination = 98.37 percent.

Tabular values for the 11- to 22-inch d. b. h. classes from equation:

$V = 0.00264\ D^2\ H + 0.81$; standard error of mean = ± 0.38 cu. ft. or ± 0.97 percent; Coefficient of determination = 97.70 percent.

Table 3. --Board-foot volume ($\frac{1}{4}$-inch International Rule) for South Florida slash pine, by diameter and total tree height 1/

D. b. h. (Inches)	Total height (feet)										
	40	45	50	55	60	65	70	75	80	85	90
	Board feet										
9	--	6	13	20	27	34	41	48	55	62	69
10	12	21	30	38	47	55	64	72	81	89	98
11	27	37	47	58	68	78	89	99	110	120	130
12	42	55	67	79	92	104	116	129	141	153	166
13	60	74	88	103	117	132	146	161	175	190	204
14	78	95	112	128	145	162	179	195	212	229	246
15	98	117	136	156	175	194	213	233	252	271	290
16	119	141	163	185	207	229	250	272	294	316	338
17	142	166	191	216	241	265	290	315	339	364	389
18	166	193	221	249	276	304	332	360	387	415	443
19	191	222	253	284	314	345	376	407	438	469	500
20	218	252	286	320	354	389	423	457	491	525	560
21	246	283	321	359	396	434	472	510	547	585	623
22	275	316	358	399	441	482	523	565	606	647	689

1/ Tabular values from equation: $V = 0.0171\ D^2\ H - 56.0$; standard error of mean = ± 2.5 bd. ft. or ± 1.29 percent; coefficient of determination = 97.63 percent.

Table 4. --Merchantable [1/] cubic-foot volume yields [2/] for slash pine stands in south Florida

Site index (Age 25)	Stand density index	Age (years)									
		15	20	25	30	35	40	45	50	55	60
		Cubic feet per acre (o.b.)									
30	100	150	360	610	880	1120	1350	1560	1760	1930	2100
	150	190	440	720	990	1250	1490	1700	1900	2070	2230
	200	250	530	830	1120	1390	1640	1850	2050	2220	2380
	250	320	640	970	1280	1560	1800	2020	2210	2380	2540
	300	420	780	1130	1450	1740	1980	2200	2390	2560	2710
40	100	270	570	880	1160	1440	1690	1910	2100	2280	2430
	150	350	690	1020	1320	1610	1860	2080	2270	2440	2590
	200	460	830	1190	1500	1800	2050	2260	2450	2620	2760
	250	590	1010	1390	1700	2010	2250	2460	2650	2810	2950
	300	760	1220	1620	1930	2240	2480	2680	2860	3010	3140
50	100	500	880	1250	1580	1860	2110	2330	2510	2680	2820
	150	640	1070	1460	1800	2080	2320	2530	2710	2870	3010
	200	830	1300	1700	2040	2320	2560	2760	2930	3080	3210
	250	1070	1580	1990	2320	2590	2820	3000	3160	3300	3420
	300	1380	1910	2320	2640	2890	3100	3270	3420	3540	3650
60	100	900	1380	1790	2130	2410	2640	2840	3000	3150	3240
	150	1160	1680	2090	2420	2690	2910	3090	3240	3380	3460
	200	1500	2030	2440	2750	3000	3200	3370	3500	3620	3690
	250	1940	2460	2840	3130	3350	3520	3670	3780	3880	3930
	300	2500	2980	3310	3550	3740	3880	3990	4090	4160	4190
70	100	1630	2160	2560	2870	3110	3300	3460	3590	3710	3800
	150	2110	2620	2990	3260	3470	3640	3770	3880	3970	4050
	200	2720	3180	3480	3700	3870	4000	4100	4190	4260	4320
	250	3520	3850	4060	4210	4320	4400	4470	4520	4570	4610
	300	4550	4660	4740	4790	4820	4850	4870	4890	4900	4910

1/ Includes merchantable cubic-foot volume of all trees 4.5 inches d.b.h. and larger to a top diameter of 3.5 inches inside bark.

2/ Tabular values from equation 1.

Table 5. --Mean annual growth[1/] for slash pine stands in south Florida

Site index (Age 25)	Stand density index	Age (years)									
		15	20	25	30	35	40	45	50	55	60
		Cubic feet per acre (o.b.)									
30	100	10	18	25	29	32	34	35	35	35	35
	150	13	22	29	33	36	37	38	38	38	37
	200	17	27	33	38	40	41	41	41	40	40
	250	22	32	39	43	44	45	45	44	43	42
	300	28	39	45	48	50	50	49	48	47	45
40	100	18	28	35	39	41	42	42	42	41	41
	150	24	34	41	44	46	47	46	45	44	43
	200	30	42	48	50	51	51	50	49	48	46
	250	39	50	56	57	57	56	55	53	51	49
	300	51	61	65	64	64	62	60	57	55	52
50	100	33	44	50	53	53	53	52	50	49	47
	150	43	54	58	60	60	58	56	54	52	50
	200	55	65	68	68	66	64	61	59	56	54
	250	71	79	80	77	74	70	67	63	60	57
	300	92	95	93	88	83	78	73	68	64	61
60	100	60	69	72	71	69	66	63	60	57	54
	150	78	84	84	81	77	73	69	65	61	58
	200	100	102	98	92	86	80	75	70	66	61
	250	129	123	114	104	96	88	82	76	71	66
	300	167	149	133	118	107	97	89	82	76	70
70	100	109	108	103	96	89	83	77	72	67	63
	150	141	131	120	109	99	91	84	78	72	68
	200	182	159	139	124	111	100	91	84	78	72
	250	235	193	163	140	124	110	99	91	83	77
	300	303	233	190	160	138	121	108	98	89	82

1/ Includes merchantable cubic-foot volume of all trees 4.5 inches d.b.h. and larger to a top diameter of 3.5 inches inside bark. Computed from data in table 4.

Table 6. --Proportion of merchantable stand volume in saw log sizes[1/] for slash pine in south Florida

Site index (Age 25)	Stand density index	Age (years)									
		15	20	25	30	35	40	45	50	55	60
		Percent									
30	200	1	2	5	8	11	14	17	20	23	25
40	200	2	5	9	15	19	24	28	31	36	39
50	200	4	11	19	26	33	40	46	51	56	61
60	200	11	25	37	48	58	67	75	82	89	90
70	200	27	54	74	88	100	100	100	100	100	100

1/ The minimum saw-log size tree was 9.0 inches d.b.h. with one 16-foot log.

Table 7. --Board-foot yields for slash pine stands in south Florida [1/]

Site index (Age 25)	Stand density index	Age (years)									
		15	20	25	30	35	40	45	50	55	60
		Board feet per acre ($\frac{1}{4}$-inch International Rule)									
30	200	--	10	50	110	200	320	460	620	780	950
40	200	10	60	170	370	640	950	1,310	1,680	2,070	2,450
50	200	50	250	660	1,250	1,990	2,820	3,690	4,580	5,470	6,340
60	200	290	1,100	2,480	4,250	6,250	8,340	10,450	12,500	14,490	16,380
70	200	1,670	4,900	9,350	14,400	19,590	24,690	29,550	34,110	38,380	42,330

1/ The minimum saw-log size tree was 9.0 inches d.b.h. with one 16-foot log.

Table 8. --Average stand diameter breast height for slash pine stands in south Florida [1/]

Site index (Age 25)	Stand density index	Age (years)									
		15	20	25	30	35	40	45	50	55	60
		Inches									
30	100	4.0	5.1	5.8	6.2	6.5	6.8	7.0	7.1	7.2	7.3
	200	2.8	3.9	4.6	5.1	5.4	5.7	5.8	6.0	6.1	6.2
	300	1.7	2.8	3.5	3.9	4.3	4.5	4.7	4.9	5.0	5.1
40	100	5.0	6.0	6.8	7.2	7.6	7.8	8.0	8.1	8.2	8.3
	200	3.9	4.9	5.7	6.1	6.4	6.7	6.8	7.0	7.1	7.2
	300	2.7	3.8	4.5	4.9	5.3	5.5	5.7	5.9	6.0	6.1
50	100	6.0	7.1	7.8	8.2	8.6	8.8	9.0	9.1	9.3	9.3
	200	4.9	6.0	6.7	7.1	7.4	7.7	7.9	8.0	8.1	8.2
	300	3.8	4.9	5.5	6.0	6.3	6.6	6.7	6.9	7.0	7.0
60	100	7.1	8.1	8.8	9.3	9.6	9.8	10.0	10.2	10.3	10.4
	200	5.9	7.0	7.7	8.2	8.5	8.7	8.9	9.1	9.2	9.3
	300	4.8	5.9	6.6	7.0	7.3	7.6	7.8	7.9	8.0	8.1
70	100	8.1	9.2	9.9	10.3	10.6	10.8	11.1	11.2	11.3	11.4
	200	6.9	8.0	8.7	9.2	9.5	9.7	9.9	10.0	10.1	10.2
	300	5.8	6.9	7.6	8.0	8.4	8.6	8.8	8.9	9.1	9.2

1/ Tabular values from equation 2.

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tion Paper No. 124 June 1961

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by

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U.S. Department of Agriculture–Forest Service
Southeastern Forest Experiment Station
Asheville, North Carolina

Yield of Virginia Pine

by

T. C. Nelson, J. L. Clutter, and L. E. Chaiken[1/ 2/]

INTRODUCTION

Virginia pine (Pinus virginiana Mill.) is the dominant species on many forest lands in Maryland, Virginia, and the Carolinas. Not many years ago Virginia pine was classed as a forest weed and commonly called "scrub pine" (6). In recent years, the good pulping qualities of its wood, its heavy yields per acre, and its acceptance as sawtimber have led to increasing interest in the productive capacity of Virginia pine by landowners.

This paper reports cubic-yield estimates of Virginia pine stands of various densities, growing on different sites, and with varying proportions of the forest stand in Virginia pine.

Yield estimates for Virginia pine have been published for other localized portions of its range. Slocum and Miller (5) constructed growth and yield tables from data gathered on the Hill Demonstration Forest in Durham County, North Carolina. Church (2) developed yield predictions for pure Virginia pine stands in Prince Georges County, Maryland, and McIntyre prepared yield tables based on data from Pennsylvania (3).

THE STUDY AREA

The study was based upon 161 plots in 51 counties in Maryland, Virginia, North Carolina, and South Carolina (fig. 1). The 105 plots in Virginia, the 36 plots in North Carolina, and the 8 plots in South Carolina were in the Piedmont on typical Piedmont soils. The twelve Maryland plots were located on coastal plain sites.

The plots were systematically located in Virginia pine stands within the counties sampled. Individual plots were tallied and used in data computations only if they contained at least 10 percent Virginia pine in the main crown canopy and there was a reasonably uniform spacing of trees throughout the plots.

1/ Research Forester, Mathematical Statistician, Southeastern Forest Experiment Station, and Professor, School of Forestry, Duke University, respectively.

2/ The computational aid of Mrs. Irma B. Ellison, Statistical Clerk, Southeastern Forest Experiment Station, is gratefully acknowledged.

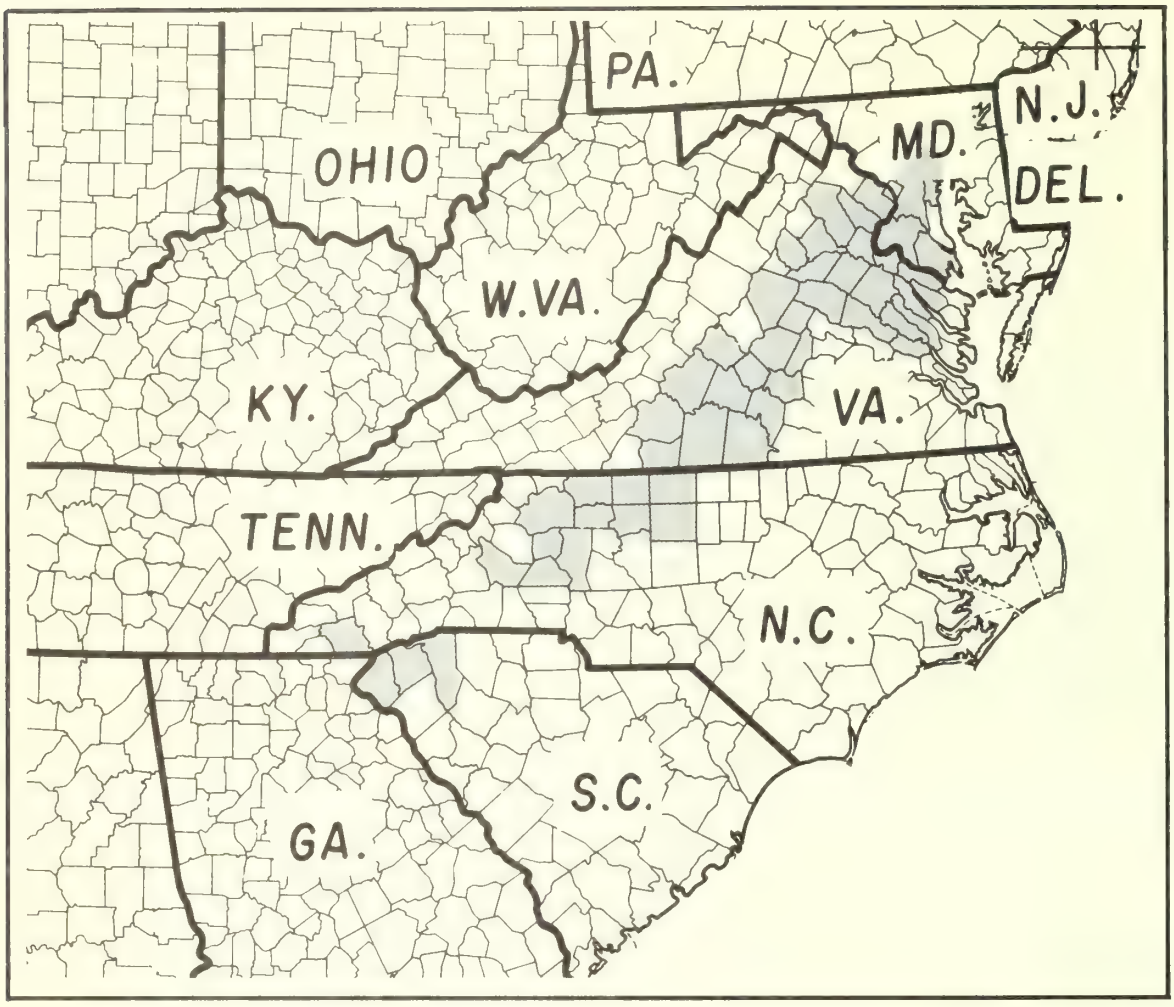

Figure 1. --Location of study plots, by counties, in Maryland, Virginia, North Carolina, and South Carolina.

The stands sampled were even-aged and varied from 10 to 70 years (fig. 2). The majority of plots (80 percent) were in old fields (fig. 3). These fields generally represent the poorest agricultural land, but sometimes are more fertile than the surrounding woodland sites.

Most of the plots showed no evidence of recent fire. Thirty-eight of the 161 plots had been grazed and the majority had indications of cutting at some time. All exposures were represented, but the majority of plots were located on slopes; only 31 plots were located on ridges.

Figure 2.--(A) A typically dense stand of Virginia pine in the North Carolina Piedmont. This 19-year-old stand contains 178 square feet of basal area per acre. (B) A 34-year-old stand near the same location with a basal area of 125 square feet per acre.

Figure 3.--Virginia pine invading an old field near Statesville, North Carolina. The seed source for these sapling-stage pines is the older, even-aged stand on the ridge.

STUDY METHODS

The analyses involved construction of volume tables, preparation of site index curves suitable for calibrating sites on the basis of heights of dominant and codominant trees at 50 years of age, and establishment of cubic-foot yields in relation to age, site index, and stand density.

Cubic Volume Table Construction

A volume table was constructed from a separate study involving 324 trees. Sample trees were measured to a top diameter outside bark of 4 inches. The data were then subjected to multiple regression analysis; the cubic-foot volume equation developed by this analysis was calculated to be:

Equation 1:

$$\text{Merchantable volume outside bark in cubic feet} = 1.237977 - 0.111164\,H - 0.250482\,D + 0.025574\,DH - 0.007355\,D^2 + 0.001358\,D^2H$$

where,

H = total tree height (in feet)

D = diameter at breast height outside bark (in inches)

Equation 1 accounted for 98 percent of the variation about the mean. Volumes calculated by this equation appear in table 1.

Table 1. --Merchantable volume outside bark of Virginia pine in cubic feet to a top diameter outside bark of 4 inches (from equation 1)

D. b. h. (inches)	Total height in feet							
	25	35	45	55	65	75	85	95
	Cubic feet							
4	0.4	0.6	0.7	0.8				
5	1.1	1.6	2.1	2.6	3.1			
6	1.8	2.7	3.6	4.5	5.4	6.3		
7	2.5	3.8	5.2	6.5	7.8	9.2	10.5	
8	3.3	5.1	6.9	8.7	10.5	12.3	14.1	15.9
9	4.1	6.4	8.7	11.0	13.3	15.6	17.8	20.1
10	5.0	7.8	10.6	13.4	16.2	19.0	21.8	24.6
11		9.3	12.6	16.0	19.3	22.7	26.0	29.4
12		10.9	14.8	18.7	22.6	26.5	30.4	34.3
13		12.5	17.0	21.5	26.0	30.5	35.1	39.6
14		14.2	19.4	24.5	29.6	34.8	39.9	45.0
15		16.1	21.3	27.6	33.4	39.2	45.0	50.7
16			24.4	30.9	37.3	43.8	50.2	56.7
17				34.2	41.4	48.6	55.7	62.9
18				37.8	45.6	53.5	61.4	69.3
19					50.0	58.7	67.3	76.0
20					54.6	64.0	73.5	82.9

Site Index Curves

Site values used in relating yield to site quality were developed from height and age data collected on each sample plot plus an additional small number of plots not represented in the yield analyses.

Site index curves based on an index age of 50 years were constructed using the coefficient of variation method as described by Osborne and Schumacher (4), and appear in figure 4 (1). Although a relationship existed between density and site index, the maximum corrections for density were too small to be given consideration. Examination of the data indicated that the regression of logarithm of height over the reciprocal of age was linear and solution by the regression method would have produced similar curves.

To establish the site index of Virginia pine within the area sampled, it is only necessary to determine the age and the average height of the dominant and codominant trees and apply this information to the curves in figure 4.

Selection of Yield Plots

The distribution of yield plots in relation to age and site index is shown in table 2. Generally, two sizes of plots were used. If the stand contained more than 800 trees per acre, the plot size was one-tenth acre; if stands contained less than 800 trees per acre, quarter-acre plots were established.

Table 2.--Distribution of yield plots by age and site index

Site class	Age class (years)					
	10 to 20	20 to 30	30 to 40	40 to 50	50 to 60	Total
	Number of plots					
50	1	2	--	--	--	3
60	28	30	14	5	1	78
70	21	25	8	6	3	63
80	4	8	4	1	--	17
Total	54	65	26	12	4	161

Plot Measurements

The following data collected at each plot location were of importance in the development of the final yield equation:

1. Sample tree measurements. Ten trees of Virginia pine (or fewer if less than 10 trees were present on the plot) were systematically selected as sample trees. The age of each sample tree was determined by increment borings or, with small sample trees, by felling the selected trees. Total height was also obtained for each sample tree.

2. Stand tally by species and 1-inch diameter classes.

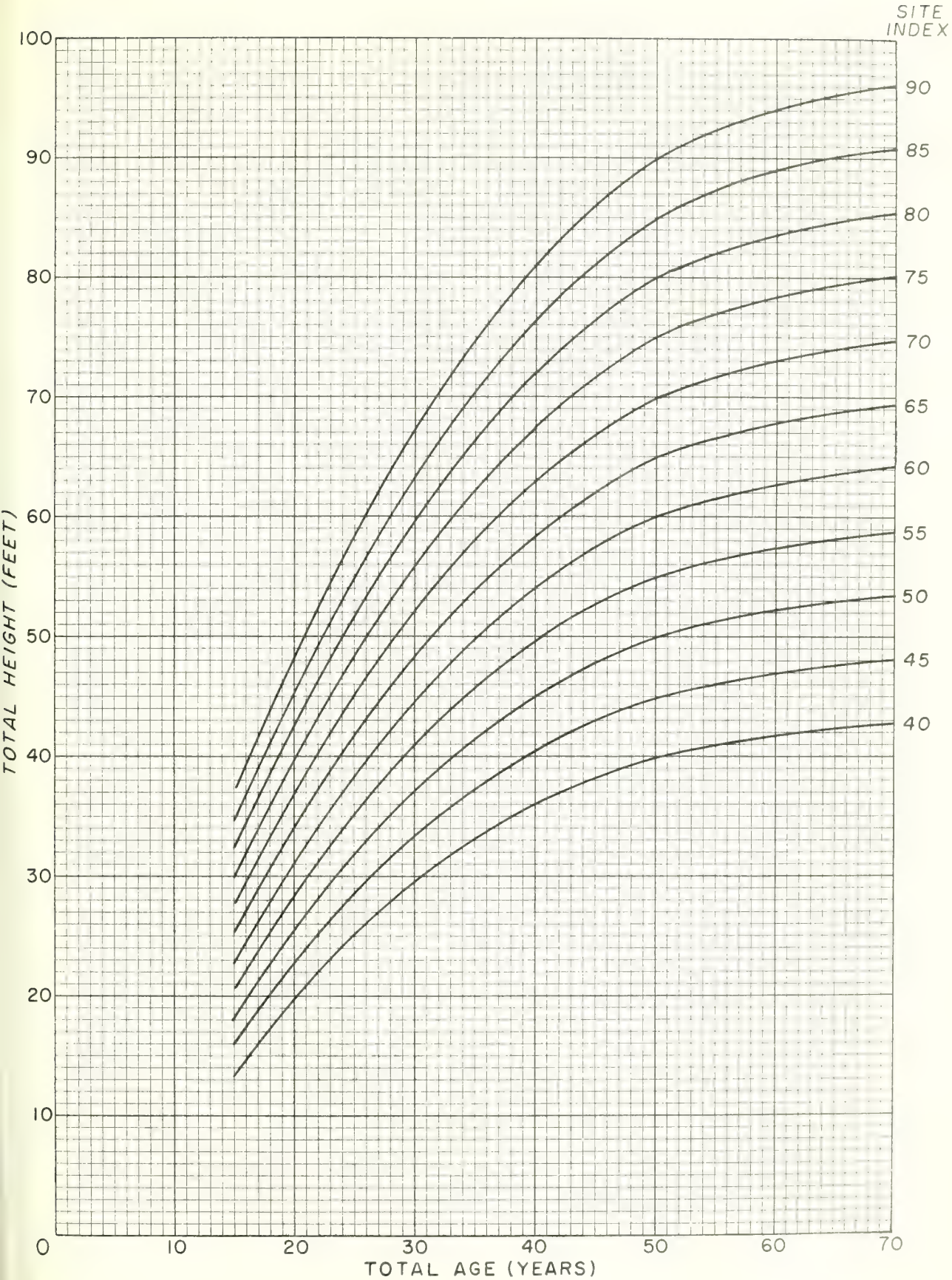

Figure 4. --Site curves at an index age of 50 years for natural stands of Virginia pine in Maryland and the Piedmont of Virginia and the Carolinas.

Calculation of Plot Volumes

Cubic foot per acre volumes were computed for the Virginia pine occurring on each plot. As a first step in this computation, a graph was prepared for each plot showing total height of the Virginia pine sample trees plotted over their diameters at breast height. These curves furnished a plot-by-plot estimate of the tree height-tree d.b.h. relationship. Per tree volume estimates for each d.b.h. class on each plot were then obtained by reading the estimated total heights from the proper height-over-diameter curve and selecting values from the cubic-foot volume tables described previously. Summations of the individual tree volumes within the plot were expanded to a per-acre basis.

Determination of Density Standards

In order to obtain precise prediction equations for yield, stand density must be measured and its effect on yield estimated. Eighty-one plots, representing conditions of average dense stocking in which Virginia pine composed at least 75 percent of the basal area, were chosen as a base for stocking. Regression analysis related total basal area per acre of all species on these plots to average stand age and site index. The regression equation derived in this analysis is shown below:

Equation 2:

$$\text{Logarithm of total basal area per acre} = 2.082746 - 4.005109(1/\text{Age}) + 0.002856\ (\text{site index})$$

This regression accounts for 83.01 percent of the variation in basal area among the 81 sample plots.

With equation 2 it is possible to predict what basal area would be considered average dense stocking for any combination of stand age and site index. Solutions of equation 2 for various combinations of age and site are given in table 3.

Table 3.--Average dense stocking in basal area per acre

Stand age (years)	Site index (feet)			
	50	60	70	80
	- - - - Square feet - - - -			
10	67	71	76	81
15	91	97	104	111
20	106	113	121	129
25	116	124	133	141
30	124	132	141	151
35	129	138	147	157
40	134	143	152	163
45	137	146	156	167
50	140	149	159	170
55	142	152	162	173
60	144	154	164	176

With the aid of table 3, the density of any given stand may be easily determined. As a first step, stand age and site index are established and the basal area of average dense stocking is obtained from the table. Density percent is then calculated as 100 times the ratio of actual total basal area per acre of all species to the basal area of average dense stocking.

Statistical Analysis

Using the logarithm of the per acre Virginia pine volume as the dependent variable (Y), multiple regression techniques were applied to data from the 161 plots to develop a yield-predicting equation based on functions of stand age, density, composition, and site.

The regression analysis indicated the following variables to be of significant importance in predicting Virginia pine yields:

the reciprocal of average stand age squared,
the logarithm of density percent,
the logarithm of percent composition where percent composition is defined as 100 times the ratio of Virginia pine basal area per acre to the total basal area per acre of the entire stand,
site index (average height of dominants and codominants at age 50).

These variables were then used to develop the final regression equation shown below:

Equation 3:

$$\text{Logarithm yield (merchantable volume outside bark in cubic feet)} = 0.098451 - 0.030055\left(\frac{100}{\text{Age}}\right)^2 + 0.28752(\text{log. density}) + 0.72820(\text{log. composition}) + 0.0236009(\text{site index})$$

Equation 3 accounts for 81 percent of the sample variation in merchantable cubic-foot yields. Solutions of equation 3 for pure Virginia pine stands of various densities and ages over a variety of sites are given in table 4.

For mixed stands, estimates of Virginia pine yields can readily be obtained by the use of composition correction factors (fig. 5). First, compute the ratio of Virginia pine basal area per acre to the total per acre basal area of the entire stand. The corresponding composition correction factor can then be selected from figure 5. Multiplication of the appropriate tabular yield value by the composition correction factor will give the corrected yield estimate. For example, a stand on site 60, age 50, 100 percent density with 60 square feet of Virginia pine per acre out of a total of 149 square feet basal area would have a 40 percent composition of Virginia pine. From figure 5, the composition correction factor would be 51 percent. The tabular yield value (table 4) would thus be reduced from 2,665 cubic feet per acre to approximately 1,359 cubic feet.

Table 4.--Yield tables for pure stands of Virginia pine in cubic feet per acre (outside bark) of merchantable volume 1/

Age (years)	Percent density					
	20	40	60	80	100	120
	- - - - - - - - - - - - - - - - Cubic feet -
SITE 55						
20	299	365	410	445	475	500
30	782	954	1,072	1,165	1,242	1,308
40	1,094	1,336	1,501	1,630	1,738	1,832
50	1,279	1,561	1,754	1,905	2,031	2,140
60	1,391	1,699	1,908	2,073	2,210	2,329
SITE 60						
20	392	479	538	584	623	657
30	1,026	1,252	1,407	1,528	1,629	1,717
40	1,436	1,753	1,969	2,139	2,281	2,403
50	1,678	2,048	2,301	2,499	2,665	2,808
60	1,826	2,229	2,504	2,720	2,900	3,056
SITE 65						
20	515	628	706	767	818	862
30	1,346	1,643	1,846	2,005	2,138	2,253
40	1,884	2,300	2,584	2,807	2,993	3,154
50	2,202	2,687	3,019	3,280	3,497	3,685
60	2,396	2,925	3,286	3,569	3,806	4,011
SITE 70						
20	676	824	926	1,006	1,073	1,131
30	1,766	2,156	2,422	2,632	2,806	2,957
40	2,472	3,018	3,391	3,683	3,928	4,139
50	2,889	3,526	3,962	4,304	4,589	4,836
60	3,144	3,837	4,312	4,684	4,994	5,263
SITE 75						
20	886	1,082	1,216	1,320	1,408	1,484
30	2,318	2,829	3,179	3,453	3,682	3,880
40	3,245	3,960	4,450	4,833	5,154	5,431
50	3,791	4,627	5,199	5,648	6,022	6,346
60	4,126	5,036	5,658	6,146	6,553	6,906
SITE 80						
20	1,163	1,419	1,595	1,733	1,847	1,947
30	3,041	3,712	4,171	4,531	4,831	5,091
40	4,257	5,197	5,839	6,342	6,763	7,126
50	4,975	6,072	6,823	7,411	7,902	8,327
60	5,414	6,608	7,425	8,065	8,599	9,062

1/ Merchantable volume of all stems 4 inches d.b.h. and over to a top diameter outside bark of 4 inches.

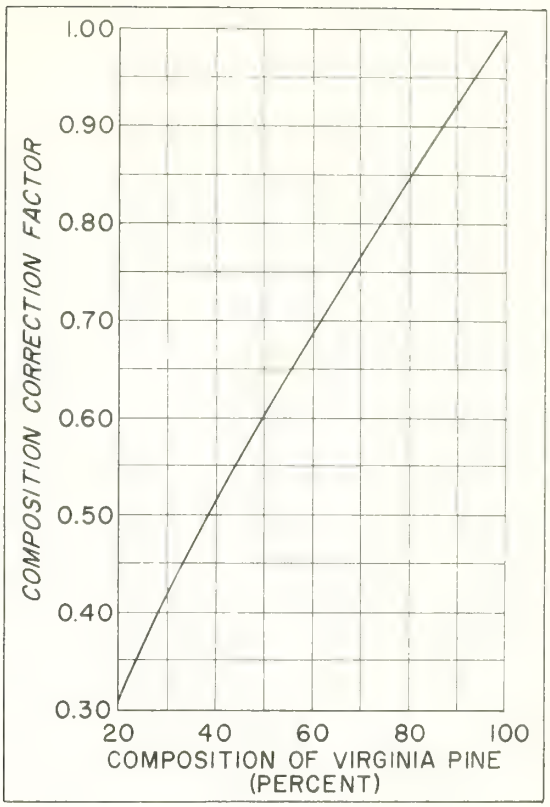

Figure 5.--Virginia pine composition correction factors for use with table 3.

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Circular Slide Rule for Calculating Wood Moisture Content

by Michael A. Taras

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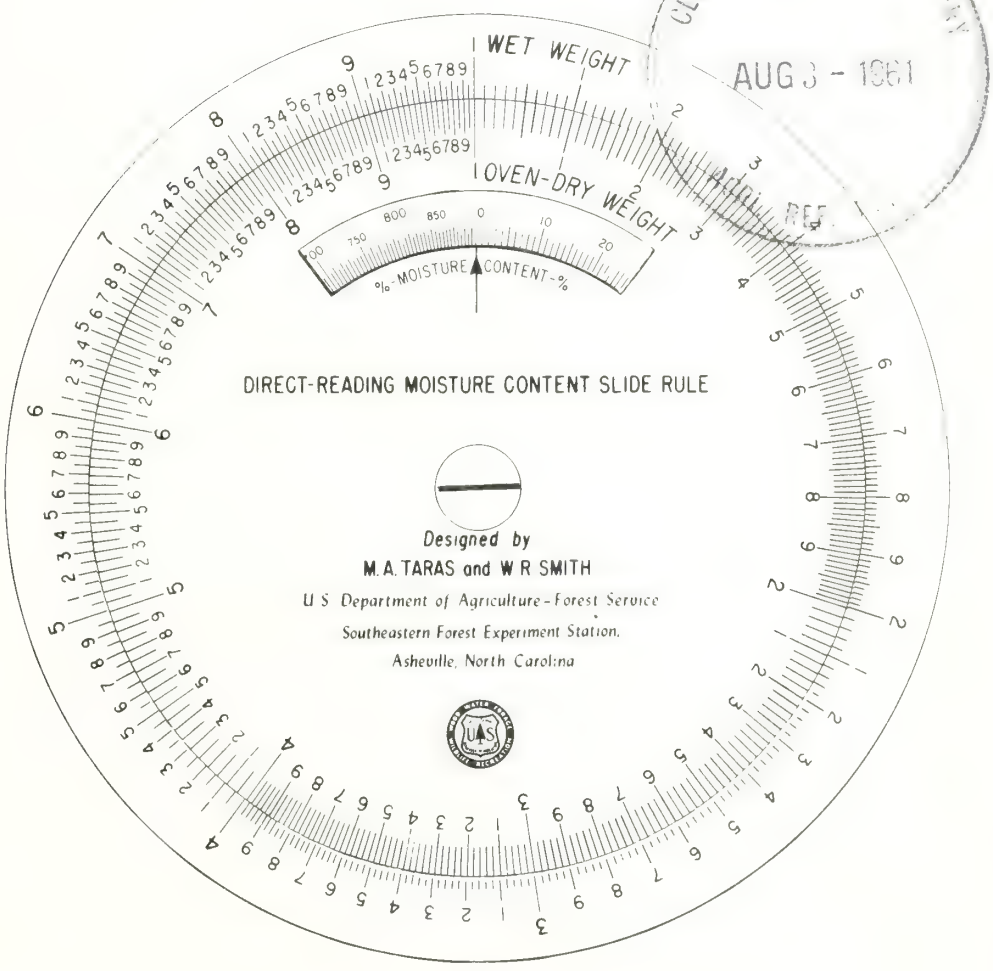


U.S. Department of Agriculture
Forest Service
Southeastern Forest Experiment Station
Asheville, North Carolina

Circular Slide Rule
for
Calculating Wood Moisture Content

by

Michael A. Taras

Moisture content is perhaps the most frequently determined and one of the most important physical properties of wood. Dry kiln operators make countless moisture determinations every day in order to establish drying schedules that will produce quality stock for the wood-using industries.

The moisture content of solid wood is expressed as a percentage of its ovendry weight.[1/] Because ovendry weight is used as a basis for calculating moisture content, the values obtained can be in excess of 100 percent. It is relatively easy to calculate moisture content after the green weight and ovendry weight have been determined; it is merely a matter of subtraction and long division. Shortcut methods have been developed for use on slide rules and calculating machines, but such instruments frequently are not available to lumberyard foremen and dry kiln operators.

The direct-reading moisture content circular slide rule was developed to simplify calculations, reduce the time of calculation, and help improve accuracy by reducing the number of mathematical steps which so frequently are the cause of errors in any computation. In the back of this publication is a working model of this slide rule. The respective parts can be cut out and put together for use. It is extremely important, in assembling the slide rule, that the center points of the disks be aligned perfectly. If they are not, the rule will give erroneous results. A standard $\frac{3}{16}$-inch Chicago center post can be obtained at any stationery store and it will fit snugly into a punched out circle at the center of the disk.

Individuals who are familiar with the operation of a conventional slide rule and know the scale calibrations can use this circular slide rule with very little instruction. Knowing the green or wet weight and the ovendry weight of a wood sample, one has only to match up the green weight on the outer scale with the ovendry weight on the inner scale and read the moisture content in percent direct from the scale that appears in the cutout window on the inner dial. Instructions for those not familiar with a slide rule are in the text which follows.

1/ Exceptions to this exist in some industries. The pulp and paper industry express moisture content based on the percentage of the green weight, and in this case the moisture content percent could never exceed 100 percent.

USING THE CIRCULAR SLIDE RULE

A few rather simple rules will make it possible for anyone to operate the Direct-Reading Moisture Content Slide Rule. Although the inner dial, marked "Ovendry weight," is smaller than the outer dial, "Wet weight," the two are identical in markings. The following explanation applies to both dials.

Figure 1

Around the outer edge of the dial are large numbers from 1 to 9. Depending upon the system of weights you are working with, these numbers can be either pounds or grams. Any of the large numbers can stand for a single unit, such as 1 pound or 1 gram; zeros may be added to raise the value in multiples of 10, 100, or 1,000. For example, the large 3 can represent 3, 30, 300, or even 3,000 grams (fig. 1).

Figure 2

The small numbers, running from 1 to 9, between each of the large numbers are used for two-digit entries. For example, if you want to locate 45 grams on the rule, first locate large number 4, then the small number 5 that is halfway between large 4 and large 5. Again, as with the large numbers, this point can also represent 4.5, 45, 450, or 4,500 grams or pounds (fig. 2).

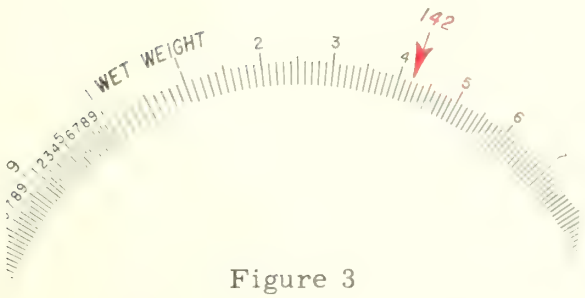


Figure 3

There are still finer divisions on the circular slide rule, and although they are not numbered, it is quite easy to know their value. For example, between large number 1 and large number 2 each smaller division has ten unnumbered lines; therefore, each fine line has a value of 1, and represents the third digit of a three-digit number. Figure 3 shows the three-digit number 142. Three-digit values can be read with reasonable accuracy over the entire rule, even though the third digit must be estimated in the area of the slide rule beyond large number 2.

Figure 4

Figure 5

Between large number 2 and large number 4, the unnumbered lines have a value of 2. For example, if you had the value 252 you first locate large 2, then the small 5 between large 2 and 3, and then locate the first unmarked division following the small number 5. This small unmarked division represents the last 2 in the value 252 (fig. 4). If the last number of a three-digit value is odd, such as 213, the process for locating the first two digits is the same as before; however, when the last digit is odd (3), you must estimate the midpoint between the first and second unmarked division. Figure 5 shows the location of the value 213.

Beyond large 4 each unnumbered line has a value of 5. Values from 1 to 4 and 6 to 9 between these unmarked divisions in this part of the slide rule must be estimated. Figure 6 shows the location of the three-digit value 573.

Figure 6

If you remember the following you should have no difficulty using the rule:

1. If the value only has one digit in it, such as 8, find the large number 8 on the rule.
2. If it has two digits, such as 45, first find the large number 4, then the small 5 which follows the large 4.
3. If it has three digits, as 155, first locate the large number 1, then the small number 5, and then the unmarked subdivision that represents 5.
4. If it has four digits, it will be reasonably accurate between large 1 and 2 but not beyond. The same procedure is followed as above; when you come to the fourth digit you must estimate between the finest divisions.

CALCULATING MOISTURE CONTENT

The basic formula used to calculate moisture content is as follows:

$$\frac{Wg - Wd}{Wd} \times 100 = \text{moisture content (percent)}$$

where

Wg = weight green

Wd = weight ovendry

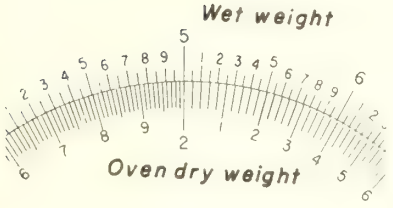
For example, a green board weighs 5 pounds. It is put in an oven and dried until it no longer loses weight, at which time it weighs 2 pounds. Then:

$$\frac{5 - 2}{2} \times 100 = \text{moisture content (percent)}$$

$$\frac{3}{2} \times 100 = \text{M. C.}$$

$1.5 \times 100 = \text{M. C.}$

150 percent = moisture content



In using the direct-reading moisture content slide rule the foregoing computations have been reduced to the simple matter of finding the wet weight, 5, on the outer scale and placing directly beneath it the ovendry weight, 2, read on the inner scale. The percent moisture content, 150, will appear opposite the arrow in the cutout window. Figure 7 shows the settings on the slide rule for this computation.

Figure 7

The moisture content scale, like the wet and ovendry scales, has a variety of divisions. From 0 to 100 each fine division represents 1 percent moisture content; fractions of 1 percent must be estimated. Between 100 and 300 each small division represents 2 percent moisture content and between 400 and 899 each small division represents 5 percent.

Listed below are a series of practice problems, covering a variety of weights, that will be helpful in learning to read the slide rule scales for the first time. The answers to the problems are in the back of this booklet.

Number	Green Weight	Ovendry Weight	Percent Moisture Content
1	8 gms.	2 gms.	_____
2	35 gms.	22 gms.	_____
3	101 gms.	39 gms.	_____
4	1800 gms.	955 gms.	_____
5	16.4 gms.	10.2 gms.	_____

CALCULATION OF OVENDRY WEIGHT

In addition to calculating the moisture content of a wood moisture section, kiln operators will also find this slide rule useful in determining the calculated ovendry weight of the kiln sample boards that are used as indicators of the moisture content of a kiln charge of lumber. To determine the calculated ovendry weight of kiln sample boards, the slide rule is operated in reverse manner to that used for determining the moisture content. In this calculation a moisture content and the green weight of the sample board must be known. The moisture content (percent) is located at the moisture content indicator in the cutout window. The green or wet weight of the sample board is then located on the outer scale and the calculated ovendry weight is read from the inner dial opposite the wet weight. For example, if the moisture content of the sample moisture sections is 60 percent and the green weight of the sample board is 21.2 pounds, the calculated ovendry weight is 13.2 pounds. This value is used throughout the kiln run to determine the moisture content of the sample board as drying progresses.

DETERMINATION OF EQUILIBRIUM MOISTURE CONTENT

If wood is exposed to a given temperature and relative humidity, it will, in time, reach a state of equilibrium with the atmospheric conditions: water will neither move into nor out of the wood. The moisture content attained by the wood under these conditions, at the point of balance, is known as the equilibrium moisture content or EMC of the wood. A knowledge of the atmospheric conditions that will give a certain EMC is essential if kiln operators are to dry wood down to a given moisture content.

Several years ago the Forest Products Laboratory published a table giving the EMC of wood for given atmospheric conditions.[2/] This EMC table has been put into a slide rule form and is printed on the back side of the direct reading moisture content slide rule. In order to use this rule all you must know is the dry bulb temperature and the wet bulb temperature; EMC values have been rounded off to the nearest one percent.

The EMC slide rule is constructed to cover a span of dry bulb temperatures from 70° to 200° F. From 70° to 130° F. the column is divided in 5-degree intervals, and from 130° to 200° F. in 10-degree intervals. Above and to the right of the column of dry bulb temperature values is a small cutout window, where the wet bulb depression value appears. The wet bulb depression is the difference between the dry bulb and the wet bulb temperature. Wet bulb depression values are listed by 1 degree up to 30° F. depression; by 2 degrees from 30° to 40° F. and by 5 degrees between 40° and 50° F.

2/ Smith, Harvey H. Relative humidity and equilibrium moisture content graphs and tables for use in kiln drying lumber. U. S. Forest Serv. Forest Prod. Lab. Rpt. 1651, 5 pp., illus. 1956.

Operation of the EMC slide rule is simple. The dial on the slide rule is turned until the desired wet bulb depression appears in the small window near the outer margin of the disk. The desired dry bulb temperature is selected from the column of values listed opposite the long cutout window, and the equilibrium moisture content is read in the cutout window opposite the dry bulb temperature selected.

Answers to Problem on page 4.

Number	Answer
1	300
2	59
3	159
4	88
5	60.7

CONSTRUCTING THE SLIDE RULE

Step 1: Carefully cut out the four disks on dotted lines.

Step 2: Following dotted lines, cut out windows on disks A and B.

Step 3: Cut out center post holes on each disk.

Step 4: Glue the back of disk C to the back of disk D.

Step 5: Place disk A over disk D.

Step 6: Place disk B over disk C.

Step 7: Insert 3/16-inch Chicago center post.

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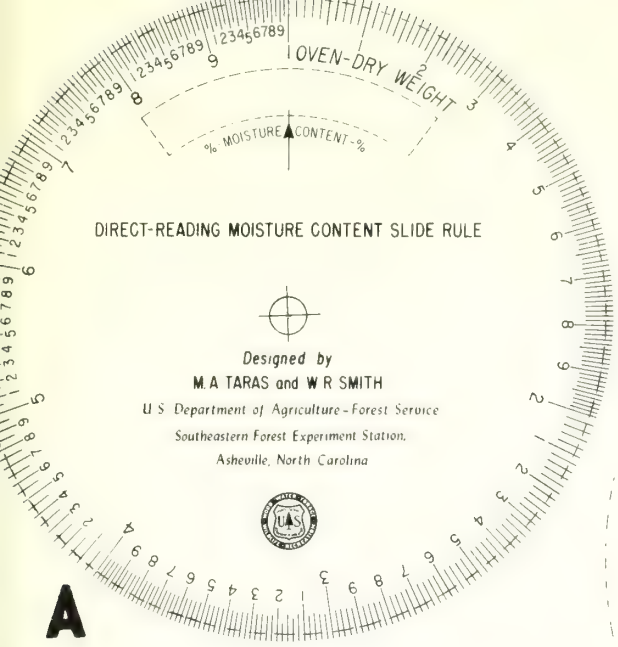
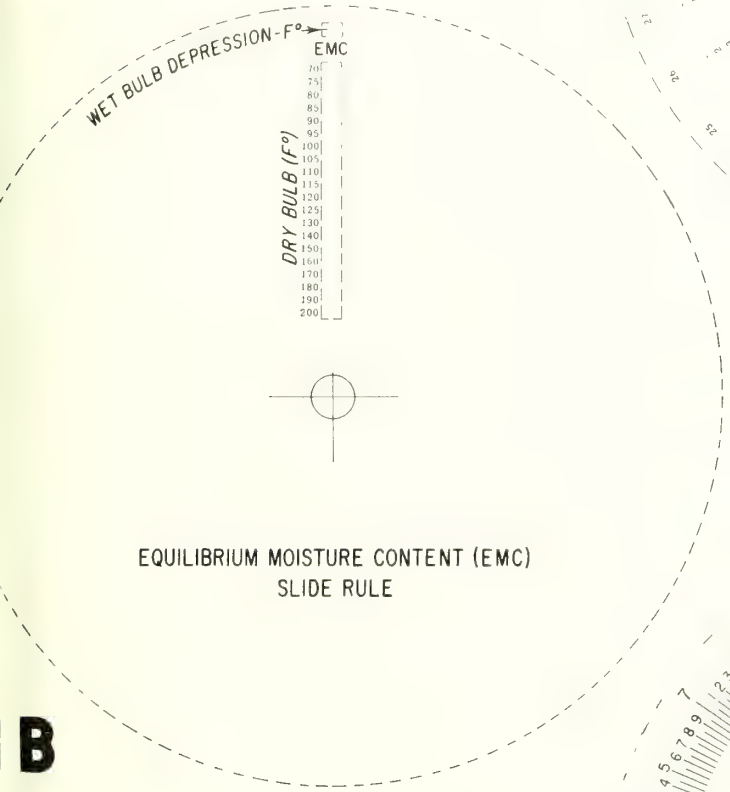
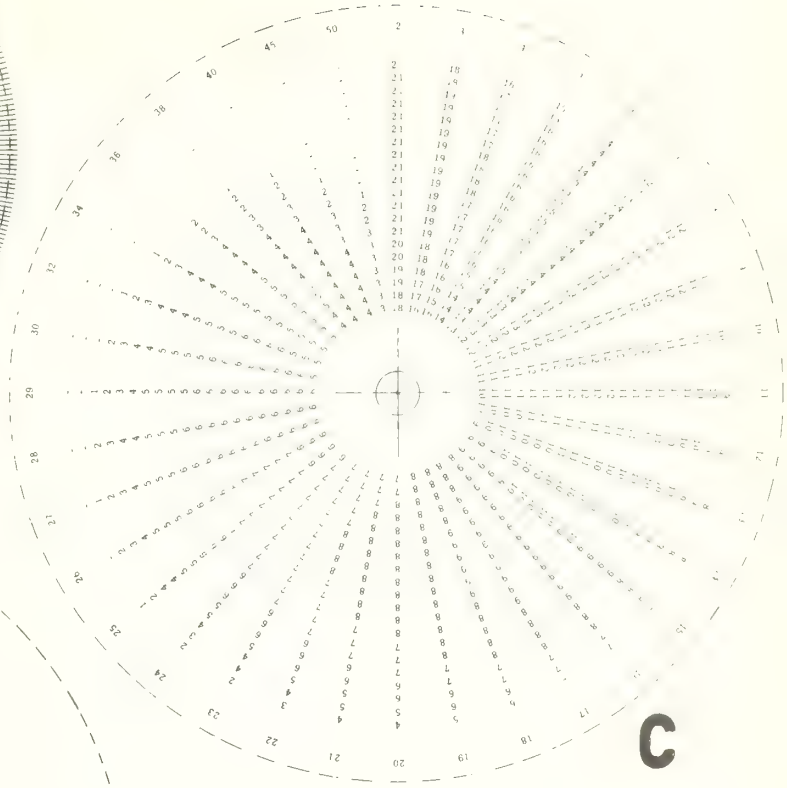
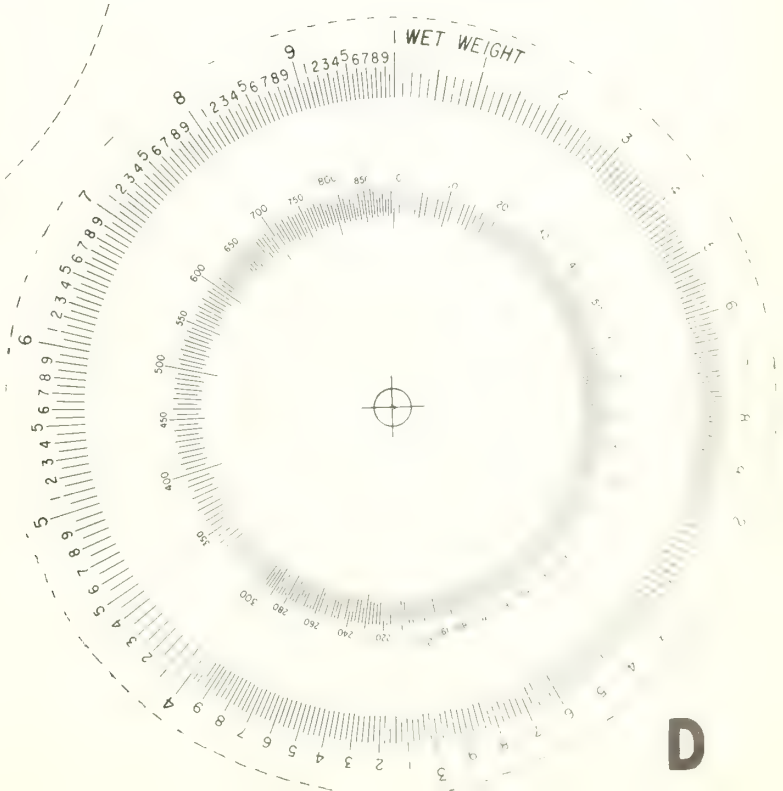

OVEN-DRY WEIGHT
% MOISTURE CONTENT-%
DIRECT-READING MOISTURE CONTENT SLIDE RULE
Designed by
M.A. TARAS and W.R. SMITH
U.S. Department of Agriculture - Forest Service
Southeastern Forest Experiment Station,
Asheville, North Carolina
A


WET BULB DEPRESSION-F°
EMC
DRY BULB (F°)
EQUILIBRIUM MOISTURE CONTENT (EMC)
SLIDE RULE
B


C


WET WEIGHT
D

Station Paper No. 117

December 1960

Publications of the Southeastern Forest Experiment Station 1921—1958

compiled by Hilda J. Brown

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Southeastern Forest Experiment Station
Asheville, North Carolina

FOREWORD

This booklet contains an alphabetical list of some 1,700 research reports put out by staff members of this Station and its cooperators. It represents the product of Federal forest research in the southeast from 1921 through 1958. During the early years, our official name was Appalachian Forest Experiment Station, with a territory consisting of Virginia, West Virginia, North and South Carolina, northern Georgia, eastern Kentucky, and eastern Tennessee. In 1946, the name was changed to Southeastern Forest Experiment Station, and the territory designated as Virginia, North and South Carolina, Georgia, and Florida.

As a result of boundary designations and small staff in the early years, the Appalachian Station worked mainly in studies of southern mountain hardwoods. The Southeastern Station list, which represents later years and an expanded staff, covers many research projects that were carried out also in the Piedmont and Coastal Plain.

The particular 37 years included in this list have brought fantastic changes, not only in the forests themselves, but in markets, viewpoints, prices, people. The chestnut has gone. The pulpmills have come. Some lands then remote are now heavily used. Trees that had no market are now valuable. Forest practices considered prohibitively expensive are becoming routine. The best research findings, then new, are now so well known we imagine we always knew them.

The list is something of a milestone in Station history and in the gradual building of forestry information for use by owners large and small. I like to think this booklet is a monument to 37 years of work by many men.

Joseph F. Pechanec

Director

Publications of the

Southeastern Forest Experiment Station

1921 — 1958

compiled by Hilda J. Brown

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Station Paper No. 126 June 1961

Growth of Outstanding Nursery Seedlings of Pinus elliottii Engelm. and Pinus taeda L.

by

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Forest Service
Southeastern Forest Experiment Station
Asheville, North Carolina

This project is in cooperation with the Georgia Forest Research Council and the Georgia Forestry Commission.

Growth of Outstanding Nursery Seedlings of *Pinus elliottii* Engelm. and *Pinus taeda* L.

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John C. Barber and David F. VanHaverbeke

Forest geneticists need to isolate individual trees with outstanding characteristics for studies of inheritance and for use in breeding programs to develop superior strains. Selection of outstanding seedlings in the nursery is one method of obtaining possible superior individuals. The feasibility of this method depends on the correlation of characteristics exhibited in the seedling stage with those at economic maturity or some other chosen point in the life of the tree.

In the South, slash pine (*Pinus elliottii* Engelm.) and loblolly pine (*Pinus taeda* L.) seedlings are grown as 1-0 stock in nurseries that produce from 20 to 100 million seedlings annually. Seedling heights normally range between 6 and 12 inches, depending upon nursery conditions. Nursery-grown trees are concentrated under near-uniform environmental conditions, minimizing the contribution of environmental factors to variation among seedlings. However, even under the best nursery conditions, soil, microclimate, or other factors may cause considerable variation in seedling growth and development.

Ellertsen (1955, 1957) has reported on nursery selection studies conducted by the Tennessee Valley Authority involving loblolly, shortleaf (*Pinus echinata* Mill.), and white (*Pinus strobus* L.) pines. Outstanding seedlings were measured and tagged. The 25 adjacent seedlings were measured and a superiority value computed for each selected seedling. Seedlings with the highest superiority rating were selected at the approximate rate of 1 per 200,000 seedlings. These seedlings were outplanted and an "average" seedling from among the 25 was used as a check. Five of every 8 selections made over a 6-year period are outgrowing the controls among the 285 planted.

In a similar study in Texas, Zobel et al. (1957) selected loblolly seedlings on a visual basis without measurement criteria. They selected outstanding, average, and inferior seedlings at each location from beds sowed with equal-sized seed of a single source. After 4 years, 90 percent of the outstanding seedlings had retained their superiority in height and diameter over average seedlings and superiority over inferior seedlings in 100 percent of the trials. Average seedlings had exceeded inferior ones in height 88 percent and in diameter 85 percent of the time.

The question of whether the superiority of individual seedlings is due to genotype, seed size, early germination, or some other factor is still unanswered. The literature indicates that large seed tend to produce large seedlings (Hough, 1952; Fowells, 1953; Righter, 1945) and that seed size affects rate of germination (Fowells, 1953). Righter (1945), using graded seed of hybrid and selfed progeny, reports that seed size is not correlated with inherent vigor and concludes that selection based on seed size would be ineffectual within a progeny. He questions whether nursery selection in any form would be profitable. Fowells (1953), working with ponderosa (Pinus ponderosa Laws.) and Jeffrey (Pinus jeffreyi Grev. & Balf.) pine, found seed size affecting seedling size up to 5 years, but not longer. At 9 years there was no difference due to seed size, but large transplants had developed into significantly taller trees than small transplants.

Brown and Goddard (1959) reported that seed size is positively correlated with seedling size within the progeny of individual trees, but not between progenies of different trees. They further conclude that if the seed of any one progeny is graded and sown in a uniform environment "...then one should expect to select inherently vigorous seedlings with more than 50 percent accuracy."

Hough (1952), working with red pine (Pinus resinosa Ait.) single-tree progeny from a racial test, reported a significant relationship between seed weight and dry weight of 2-0 seedlings. He reported a highly significant correlation of average first year leader growth after planting with average green weight of 14-tree bundles of 2-1 stock. The regressions of total height at 5 years and again at 10 years with green weight were significant. He found a significant difference in the slopes of the 5-year and 10-year regressions which indicated that the heavier seedlings grew faster during the second 5-year period.

Lindquist (1948) found a correlation of branching characteristics in 1-1 Scotch pine (Pinus sylvestris L.) with branch forms of the parent trees. He also suggests that slow-growing seedlings be rejected to avoid using stock with inherently slow growth rates.

It should be pointed out that the work cited above, with the exception of Ellertsen, Brown and Goddard, and Zobel et al., was done with northern or western species. These species require several years in the nursery or transplant bed and have relatively slow juvenile growth when compared with slash and loblolly pine.

METHODS

In the fall of 1954 the four nurseries of the Georgia Forestry Commission were screened for outstanding seedlings. The selector walked through the nursery and observed 4 to 8 beds at a time, depending on species and conditions. Whenever an outstanding seedling was noted, a 30-inch cane was stuck in the ground beside it. Outstanding seedlings on outside rows, adjacent to failed areas or areas of low density, or in clumps of 3 or more, were automatically rejected. The criteria were flexible; height was the main basis for selection, with diameter, buds, or any other mark of vigor being considered. Totals of 582 slash and 571 loblolly seedlings were selected and lifted. This approximated a rate of 1 per 146,000 for slash and 1 per 44,000 for loblolly. The seedlings were lifted with spades and an "average" seedling was also taken from the same square foot of nursery bed for a control. The paired seedlings were kept together and subsequently planted adjacently in Twiggs County, Georgia, 1/ on an upland old-field site (figures 1 and 2).

1/ The planting site for this study was provided through the cooperation of Georgia Kraft Company.

Figure 1. --Loblolly pine seedlings after 2 years in the field. Row B is control seedlings with corresponding selected seedlings in row A. Row C is selected seedlings.

Figure 2. --Slash pine seedlings after 2 years in the field. Row B is control seedlings with corresponding selected seedlings in row A. Row C is selected seedlings.

RESULTS

At the end of the first growing season, the survival of seedlings in the select and control groups was nearly identical (table 1). Each year the real difference in average heights has increased (fig. 3). After 4 years selected loblolly pine seedlings were 16 percent and slash pine were 19 percent taller than the controls.

Table 1. --Survival and average heights of seedlings for four growing seasons in the field

Species	Group	Planted	1 year		2 years		3 years		4 years	
			Survival	Average height	Survival	Average height	Survival	Average height	Survival	Average height
		Number	Percent	Feet	Percent	Feet	Percent	Feet	Percent	Feet
Loblolly pine	Control	571	76	1.26	73	2.43	73	4.92	70	8.10
	Select	571	76	1.80	75	3.19	75	5.98	72	9.36
Slash pine	Control	582	69	1.33	69	2.56	69	5.48	67	9.43
	Select	582	69	1.86	69	3.70	68	6.99	65	11.24

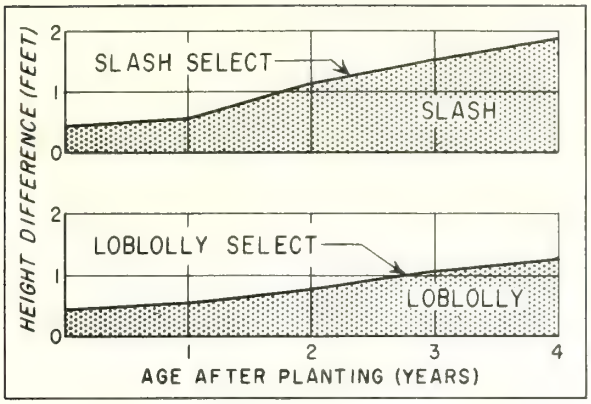

Figure 3. --Differences in average heights between selected and control seedlings for slash and loblolly pines.

Height data at 4 years for each species were subjected to statistical analysis. Only paired seedlings were used. The height of each select seedling was corrected by the difference in height at the time of planting. A "t" test of the adjusted differences indicated that select seedlings were taller than the controls, and that the difference was significant with 99 percent confidence.

The height frequency distribution curves for each species are strikingly similar with a large area under each curve having no overlap (fig. 4).

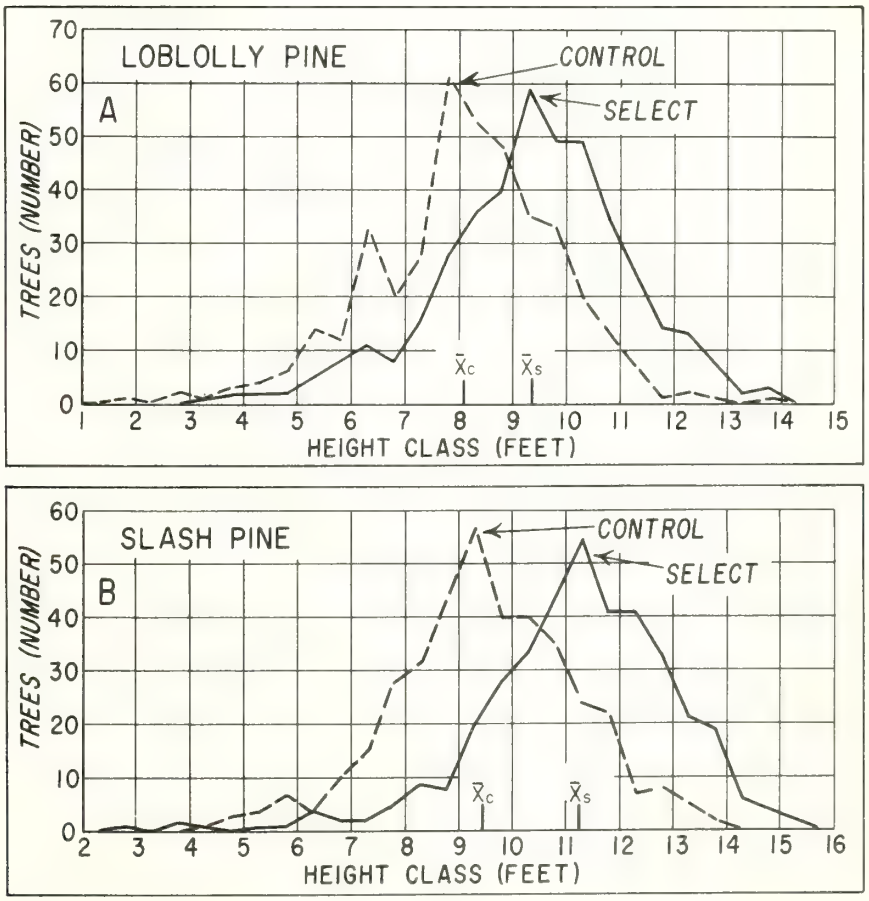

Figure 4. --Height frequency distribution of all loblolly pine seedlings (A) and all slash pine seedlings (B) after 4 years in the field.

The frequency distributions of the heights of selected seedlings, expressed as percent of height of control for each pair, are similar for both species (fig. 5). About 20 percent of the selected seedlings are exceeded by their controls, and about 30 percent exceeded their controls by more than 30 percent in height (fig. 6).

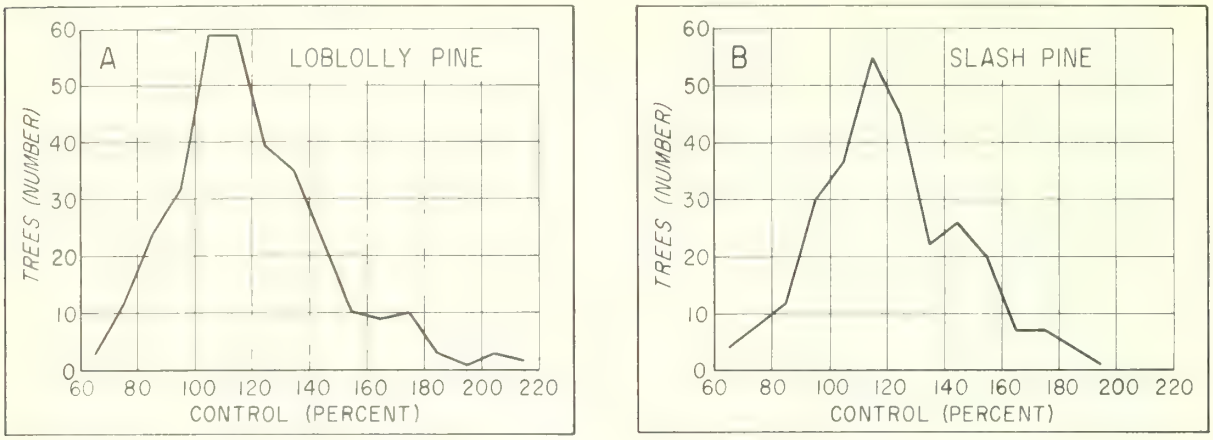

Figure 5. --Frequency distribution of height of selected seedling expressed as percent of control. (A) Loblolly pine 4 years in the field (340 pairs). (B) Slash pine 4 years in the field (289 pairs).

Figure 6. --Slash pine after 5 years in the field. The row on the right contains control seedlings with the corresponding select seedlings on the left. The difference in average heights between the rows is typical of the performance of the two groups.

Following the fourth growing season, fusiform rust (Cronartium fusiforme (A. & K.) Hedgc. & Hunt) infection was tallied by number and location of cankers (table 2). Selected seedlings of slash pine show no greater percentage of total infected trees than controls. Selected seedlings of loblolly have a higher percentage of infection than controls. For trees with stem cankers there is little difference between groups within species. The number of cankers per infected tree is slightly higher for selected seedlings of both species. The number of ramicorns 2/ per infected tree is higher among select than control seedlings. In view of the larger crowns on selected seedlings, it might be expected that there would be more infections on these trees because of the greater chance for a rust spore to land, germinate, and infect successfully.

Except in the control loblolly, the percentages of rust-free trees in all height classes are similar, indicating that the more vigorous trees are not more susceptible to rust per se (fig. 7). This may give a better opportunity to select for a combination of several desirable characteristics.

This study was not designed to determine differences between species. Although planted on the same tract, the slash and loblolly are not contiguous and probably have different microclimate and soil conditions. Therefore, any comparisons between species may be erroneous.

2/ A ramicorn is a branch of abnormally large size occurring at an acute angle to the stem, and in this instance associated with a canker. Ramicorns create large knots and are very slow to self prune.

Table 2. --Fusiform rust infection 4 years after outplanting 1/

Species	Group	Trees	All trees			Trees with branch cankers		Trees with branch and stem cankers		
			Infected	Cankers per tree	Ramicorns per tree	Trees with cankers 2/	Cankers per tree	Trees with cankers 2/	Branch cankers per tree	Stem cankers per tree
		Number	Percent	Average number		Percent	Average number	Percent	Average number	
Loblolly pine	Control	399	79	5.0	1.6	34	3.4	41	5.0	1.6
	Select	414	86	6.2	1.8	40	3.9	44	6.5	1.8
Slash pine	Control	391	75	5.0	2.4	32	2.6	40	5.7	1.6
	Select	381	76	5.7	2.8	34	3.5	39	6.2	1.7

1/ None of the differences in rust infection of control and select seedlings were statistically significant for either species.

2/ The difference between the sum of these percentages and the total percent infected represents trees which have stem cankers but not branch cankers.

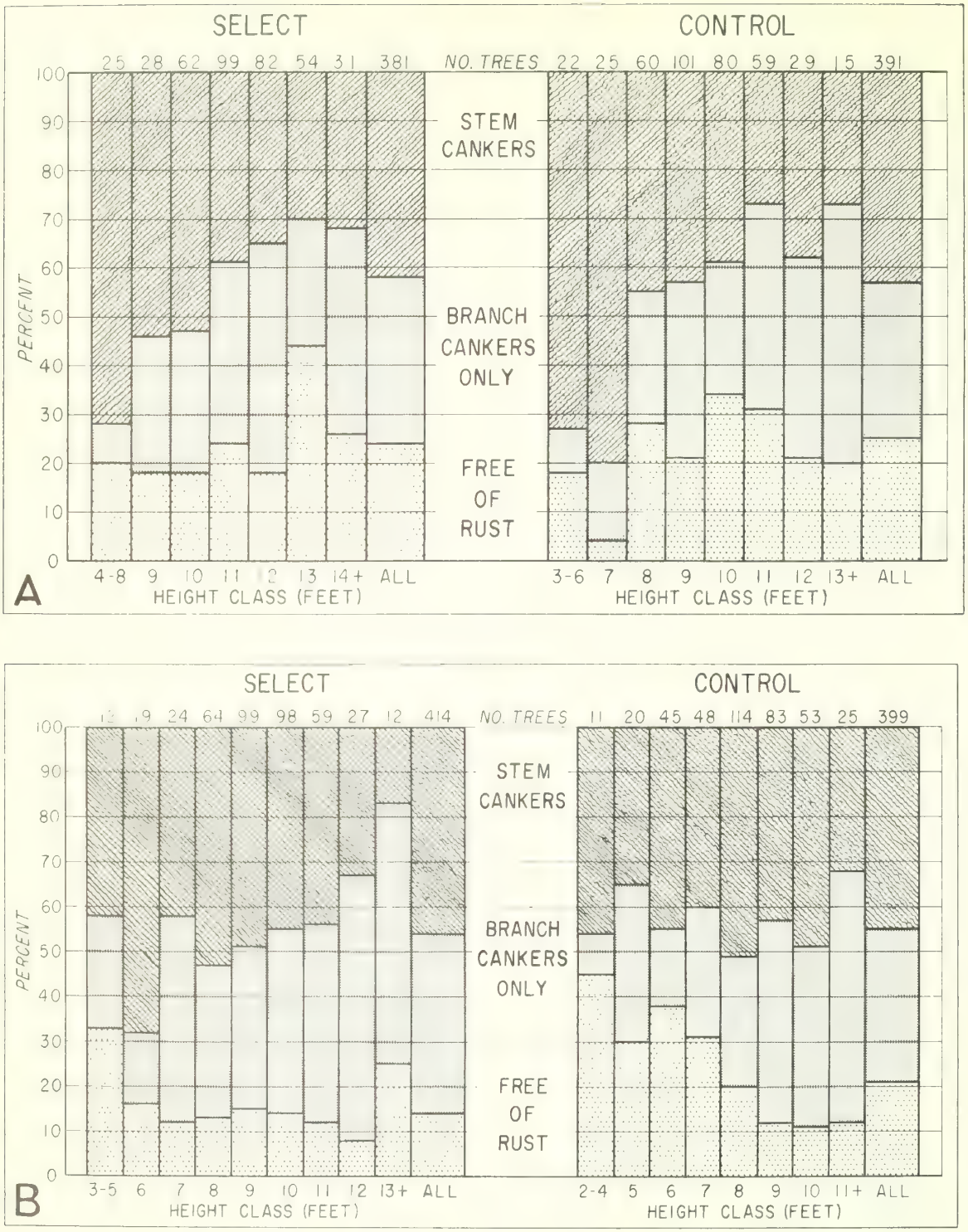
SELECT
CONTROL
NO. TREES
25 28 62 99 82 54 31 381
22 25 60 101 80 59 29 15 391
PERCENT
STEM CANKERS
BRANCH CANKERS ONLY
FREE OF RUST
4-8 9 10 11 12 13 14+ ALL
3-6 7 8 9 10 11 12 13+ ALL
HEIGHT CLASS (FEET)
A
SELECT
CONTROL
NO. TREES
12 19 24 64 99 98 59 27 12 414
11 20 45 48 114 83 53 25 399
PERCENT
STEM CANKERS
BRANCH CANKERS ONLY
FREE OF RUST
3-5 6 7 8 9 10 11 12 13+ ALL
2-4 5 6 7 8 9 10 11+ ALL
HEIGHT CLASS (FEET)
B

Figure 7. --Fusiform rust infection by height classes in (A) slash pine and (B) loblolly pine 4 years after planting.

The form of individual trees is quite varied in terms of straightness of stem and length, diameter, angle, and number of branches. To obtain an estimate of crown form, the 50 tallest select slash pines were measured and also the 50 select slash trees nearest the mean height for the select group. Each tree was examined and two determinations of the ratio of crown width at one-half height to total height were made and averaged. Each stem was also classified for straightness into one of three groups. There is little difference in form between the two groups, though the difference in average height is 22.5 percent (table 3).

Table 3. --Distribution of crown width and stem straightness in two groups of the selected slash pine seedlings

Crown width class 1/	Stem straightness class 2/			Total
	Straight	Slight deviation	Crooked	
	Number			Number
AVERAGE TREES--11.24 FEET				
Less than 0.30	11	2	-	13
0.31 to 0.40	14	12	1	27
Greater than 0.41	3	5	2	10
Total	28	19	3	50
TALLEST TREES--13.78 FEET				
Less than 0.30	7	4	1	12
0.31 to 0.40	13	14	3	30
Greater than 0.41	4	4	-	8
Total	24	22	4	50

1/ $\frac{\text{Crown width (feet)}}{\text{Tree height (feet)}}$

2/ Straight: No noticeable deviation from a perfectly straight stem.
Slight deviation: Slight sweep or crook which will not affect merchantability for any product.
Crooked: Crook or sweep severe enough to be noticeable when merchantable size is reached.

INTERPRETATION

In view of the literature on nursery selection and the data herein presented, we conclude that selection of outstanding slash and loblolly pine seedlings in the nursery is a feasible means of isolating outstanding trees for vigor. Our criteria were not as rigid as those of T. V. A.; however, we have obtained all the seedlings their methods would have selected plus many more. The final ratio of 1:44,000 for loblolly is probably higher than desirable because normally loblolly pine beds show more irregularity than slash, thus making accurate selection for vigor more difficult. Because of this, we would expect our selection of loblolly pine seedlings to be less effective.

Using a 3-man crew (one man selecting, two lifting) a nursery of 30 to 50 million trees capacity can be scanned in a day, and if the beds are reasonably uniform, they will yield 150 to 200 seedlings. Only a small percentage of these need to prove superior to justify the expenditure of manpower and money involved. In view of the limited number of outstanding seedlings evident in nursery beds, it is not feasible to use them directly for plantations or seed orchard establishment.

These selected seedlings are only the first step in isolating material. The test plantations established with them will be observed and further selections made for combinations of desirable traits (fig. 8).

Our data indicate a wide range of fusiform rust infection, ranging from none to more than 15 cankers per tree. It would be difficult to explain these differences in terms of "escapes" or other chance phenomena. Some of the most vigorous trees are free of rust, though more than three-fourths of the total number of trees are rust infected. The rust-free trees are apparently randomly scattered throughout the plantations.

The form of the faster growing slash pines is about the equivalent of that in slower growing material and indicates that crown form is probably not highly correlated with vigor. Form estimates were not made in loblolly pine because of the confounding of tip moth damage.

Nursery selection appears to offer good potential as a means of isolating superior individuals for breeding purposes. If the performance of the selected seedlings continues as it has the first 4 years, the degree of success will be high enough to justify the expenditure of considerable effort to isolate material in the nurseries. Thousands of seedlings can be screened rapidly and selection criteria can be adjusted to obtain populations of the desired size. However, it will probably be feasible to select only for vigor. Selection for characters, such as stem form, wood quality, and pest resistance will probably have to be delayed until the trees are well established in the field. The relative efficiency of selection for several characters simultaneously may be less here than by other methods.

SUMMARY

Based on results after 4 years of growth, selection of outstanding nursery seedlings is a feasible means of isolating trees of unusual genetic constitution. On the average, 4-year-old selections of loblolly and slash pines exceed their controls in height by 16 percent and 19 percent, respectively. Statistical tests indicate the differences are highly significant. Records of fusiform rust infection show no difference in percent of trees infected between the slash groups, and a slightly higher proportion of selected loblolly infected. For both species there were more cankers per tree on the infected outstanding seedlings, though this may be attributed in part to their larger size. The form of the faster growing slash pine selections appeared no different from a slower growing group. Survival of select and control groups was about the same for both species.

Figure 8. --Very vigorous slash pine after 4 years in the field. The select seedling on left corresponds to the control on the right. The select seedling is free of fusiform rust, growing rapidly, and has "average" form. (Pole is 12.0 feet.)

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Agriculture--Asheville

Station Paper No. 127 July 1961

Merchantable Cubic-Foot Volume Growth in Natural Loblolly Pine Stands

by

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and K.B. Trousdell

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Southeastern Forest Experiment Station
Asheville, North Carolina

Merchantable Cubic-Foot Volume Growth in Natural Loblolly Pine Stands

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T. C. Nelson, T. Lotti, E. V. Brender, and K. B. Trousdell [1/]

INTRODUCTION

This is a second progress report of a regional study on growing space requirements for natural stands of loblolly pine (Pinus taeda L.). It considers cubic-foot growth in relation to age, site, and stand density. The first report of this study was published as Southeastern Forest Experiment Station Paper 97.

The over-all objective of this study is to measure the effects of stand density upon volume production; this report, however, deals only with periodic cubic-foot increment. Stand densities were attained naturally or imposed artificially by cutting over a broad span of ages upon a wide range of sites. It was recognized that one of the most elusive forest management problems has been allocation of reserve growing stock for optimum growth during intermediate stand ages. Most of the approaches to this problem to date have been through thinning studies, and while these studies have provided case histories of the immediate benefits of thinning, they have contributed little to the notion that a stand density for optimum growth may exist for any combination of age and site. Nor have they contributed to the further thought that optimum growing space for a given site and age is capable of being related and translated into economic considerations, such as product objective, maximum earnings, and sound financial policy.

The cubic-foot growth data obtained during the second 5-year growth period of this study are reported in this paper. Obviously, too short a period of record has occurred to allow total production analyses at this time; such analyses require data from additional cutting cycles. This paper, however, provides an addition to our knowledge of the growth relations of natural loblolly pine stands and provides growth predictions which can be translated into stand prescriptions.

1/ T. C. Evans and K. F. Wenger prepared the work plan and amendments for this study. Contributions to planning and analyses by J. L. Clutter and P. C. Guilkey of the Southeastern Forest Experiment Station staff are gratefully acknowledged.

METHODS

Circular $\frac{1}{4}$-acre plots with $\frac{1}{2}$-chain isolation strips were established in 152 plots in four widely separated locations representing a wide range of site indices, stand densities, and ages. Plots were selected originally in 20- to 60-year-old stands with a range in site index of slightly less than 60 feet to more than 100, and a uniformity of site index that did not vary more than 10 feet within the plot boundaries. Densities ranged from 40 to 130 percent of full stocking (density percent [2]) (6). Stands were rejected if the loblolly pine was not essentially pure, undisturbed, even-aged, uniformly spaced, and insect and disease free.

Plots were established in Georgia on the Hitchiti Experimental Forest in the lower Piedmont, in South Carolina on the Santee Experimental Forest and the Westvaco Experimental Forest, [3] both locations in the lower coastal plain, and in Tidewater, Virginia, on the Camp Experimental Forest [4] during 1948-1950.

All pine stems 0.6 inch d. b. h. and larger were tallied to the nearest tenth-inch in diameter. Hardwoods 4.6 inches d. b. h. and larger, predominantly in stand understories, were eliminated by poisoning. Site index was determined by conventional site index measurements, using Coile's (2) site index curves. Earlier data from the Hitchiti, Santee, and Camp Experimental Forests provided volume tables which were used in computing merchantable cubic-foot volume outside bark of stems to a 4-inch top diameter outside bark for trees 4.6 inches d. b. h. and larger.

Approximately one-third of the plots were cut to specified residual densities immediately following plot establishment. It was necessary to modify the thinning method (from below) somewhat in order to obtain uniform spacing of residual stems and to remove undesirable trees in all crown classes. Thus, clustering was minimized and each tree occupied a growing space commensurate with its size class under the stocking regime assigned to the plot.

The thinned plots were rethinned as necessary to keep them in the same density class and another one-third received an initial thinning at the end of the first 5-year growth period. The distribution of plots at the beginning of the second 5-year growth period by age, site, and stand density is shown in tables 1 and 2. All plots were remeasured following the fifth and

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2/ Density percent expresses the basal area of a stand of given average diameter as a percentage of the basal area of well-stocked stands of the same average diameter.

3/ Maintained by the West Virginia Pulp and Paper Company near Georgetown, S. C.

4/ Maintained in Sussex County, Virginia, by the U. S. Forest Service, in cooperation with the Union Bag-Camp Paper Corporation.

Table 1. --Distribution of thinned plots at beginning of second five-year period according to site index, age, and density percent

Site index (feet)	Age class	Density percent								
		11 to 20	21 to 30	31 to 40	41 to 50	51 to 60	61 to 70	71 to 80	81 to 90	91 to 100
	Years	Plots								
60	21 to 30	--	--	--	--	1	--	--	--	--
	31 to 40	--	1	3	2	--	1	3	1	--
	41 to 50	--	1	--	3	1	1	1	--	--
	51 to 60	--	2	--	--	2	--	--	--	--
	61+	--	--	--	--	1	--	--	--	--
70	21 to 30	--	1	1	1	--	1	--	--	--
	31 to 40	1	2	1	--	1	1	3	1	--
	41 to 50	--	--	1	--	1	--	--	--	--
	51 to 60	1	1	1	2	2	1	--	--	--
	61+	--	--	--	--	--	1	--	--	--
80	21 to 30	--	1	1	1	--	1	--	--	--
	31 to 40	1	2	2	--	1	1	3	1	--
	41 to 50	--	--	1	--	1	--	--	--	--
	51 to 60	1	1	1	2	2	1	--	--	1
	61+	--	--	--	--	--	1	--	--	--
90	21 to 30	--	--	--	1	--	1	1	--	--
	31 to 40	--	--	1	--	1	--	--	--	--
	41 to 50	--	1	--	--	2	1	2	--	--
	51 to 60	--	--	1	1	1	1	2	1	--
	61+	--	--	--	--	--	--	--	--	--
100	21 to 30	--	--	1	--	1	1	1	--	--
	31 to 40	--	--	--	1	--	--	--	1	--
	41 to 50	--	--	--	--	1	--	--	--	--
	51 to 60	--	--	--	--	1	1	--	--	--
	61+	--	--	--	--	--	--	--	--	--

Table 2. --Distribution of unthinned plots at beginning of second five-year period according to site index, age, and density percent

Site index (feet)	Age class	Density percent							
		41 to 50	51 to 60	61 to 70	71 to 80	81 to 90	91 to 100	101 to 110	111 +
	Years	Plots							
60	21 to 30	--	--	--	--	--	--	--	--
	31 to 40	1	--	--	4	1	1	--	--
	41 to 50	--	--	--	2	--	--	--	--
	51 to 60	--	--	2	1	1	--	--	--
	61+	--	--	2	2	--	--	--	--
70	21 to 30	--	--	--	--	1	--	--	--
	31 to 40	--	--	--	1	--	--	--	--
	41 to 50	--	--	--	--	1	--	1	--
	51 to 60	--	--	--	--	1	--	--	--
	61+	--	--	1	--	--	1	--	--
80	21 to 30	--	2	1	1	--	--	1	--
	31 to 40	--	--	1	--	2	--	--	1
	41 to 50	--	--	1	1	--	--	1	--
	51 to 60	--	--	--	--	--	1	--	--
	61+	--	--	--	--	1	--	--	--
90	21 to 30	--	--	--	1	--	--	--	1
	31 to 40	--	--	--	--	--	--	--	--
	41 to 50	--	--	2	--	--	--	--	--
	51 to 60	--	--	--	2	--	--	--	--
	61+	--	--	--	--	--	--	--	--
100	21 to 30	--	--	--	--	--	--	--	--
	31 to 40	--	--	--	--	--	--	--	--
	41 to 50	--	--	1	1	1	--	--	1
	51 to 60	--	--	--	--	--	1	--	--
	61+	--	--	--	--	--	--	--	--

tenth growing seasons. Growth was expressed as merchantable net periodic annual increment and the initial screening of all 511 combinations of the independent variables for an estimating equation was fitted to the following form:

$$Y = b_0 + b_1(1/A) + b_2(S) + b_3(D) + b_4(D^2) + b_5(S/A) + b_6(D/A) + b_7(D^2/A) + b_8(SD) + b_9(SD^2)$$

Where Y = periodic 5-year net annual merchantable growth in cubic feet per acre of trees 4.6 inches d. b. h. and larger

A = age of stand in years at the beginning of the 5-year period
S = site index of stand
D = density of the stand
b with subscripts = coefficients derived from the data

RESULTS

Thinned Stands

Analyses of the 5- to 10-year growth data have confirmed many of Wenger's results (7). In the thinned stands, cubic-foot growth was related to age, site index, and stand density expressed as density percent (6) and as basal area per acre. Table 3 shows basal area equivalents for a wide range of density percents.

Table 3. --Basal areas per acre in relation to percent of theoretical full stocking for various diameter classes

Average d.b.h. (inches)	Percent stocking											
	20	30	40	50	60	70	80	90	100	110	120	130
	Square feet per acre											
4	24	36	47	59	71	83	95	107	119	131	142	154
6	28	42	56	70	86	98	112	126	140	154	168	182
8	31	46	61	77	92	107	122	138	153	168	183	199
10	32	48	64	81	97	113	129	145	161	177	193	210
12	33	50	67	84	100	117	134	150	167	184	201	217
14	34	52	69	86	103	120	138	155	172	189	206	223
16	35	53	70	88	105	123	140	158	175	193	210	228

Using density percent as an expression of stand density, the relations of growth in cubic feet per acre to stand age, site index, and stand density were as follows:

(Equation 1)

$$\text{Cubic-foot growth} = 205.0 + 0.26005\left(\frac{10{,}000}{\text{Age}}\right) - 0.03087(\text{Density Percent})^2$$

$$+ 0.05824(\text{Site} \times \text{Density Percent}) - 8.11990(\text{Site}) + 0.05328(\text{Site})^2$$

Where density = percent of theoretical full stocking after thinning at the beginning of the 5-year period

Of the nine independent variables screened in the original equation, only the first three expressed in Equation 1 proved significant. The last two terms in the equation were added to eliminate curvilinearity of residuals when plotted in relation to site. This expression explained over 78 percent of the variation in annual cubic-foot growth. Results are shown in table 4 and expressed graphically in figure 1.

Table 4. --Relation of periodic annual cubic-foot growth to age, site, and density percent, in thinned stands

Age	Density percent								
	20	30	40	50	60	70	80	90	100
	Cubic feet								
SITE 60									
30	--	--	87	94	95	90	78	61	
40	--	--	65	72	73	68	57	39	
50	--	--	52	59	60	55	44	26	
60	--	--	43	51	52	46	35	18	
SITE 70									
30	--	79	98	111	118	118	113	101	
40	--	57	76	89	96	97	91	80	
50	--	44	63	76	83	84	78	67	
60	--	36	55	68	75	75	70	58	
SITE 80									
30	64	95	120	139	151	158	158	152	140
40	42	73	98	117	130	136	137	131	119
50	29	60	85	104	117	123	124	118	106
60	21	52	77	96	108	115	115	109	97
SITE 90									
30	85	122	153	177	196	208	214	214	208
40	63	100	131	156	174	186	193	192	186
50	50	87	118	143	161	173	180	179	173
60	42	79	109	134	153	165	171	171	165
SITE 100									
30	117	159	197	226	251	269	281	287	286
40	95	138	175	205	229	247	259	265	265
50	82	125	162	192	216	234	246	252	252
60	73	116	154	183	208	226	238	243	243

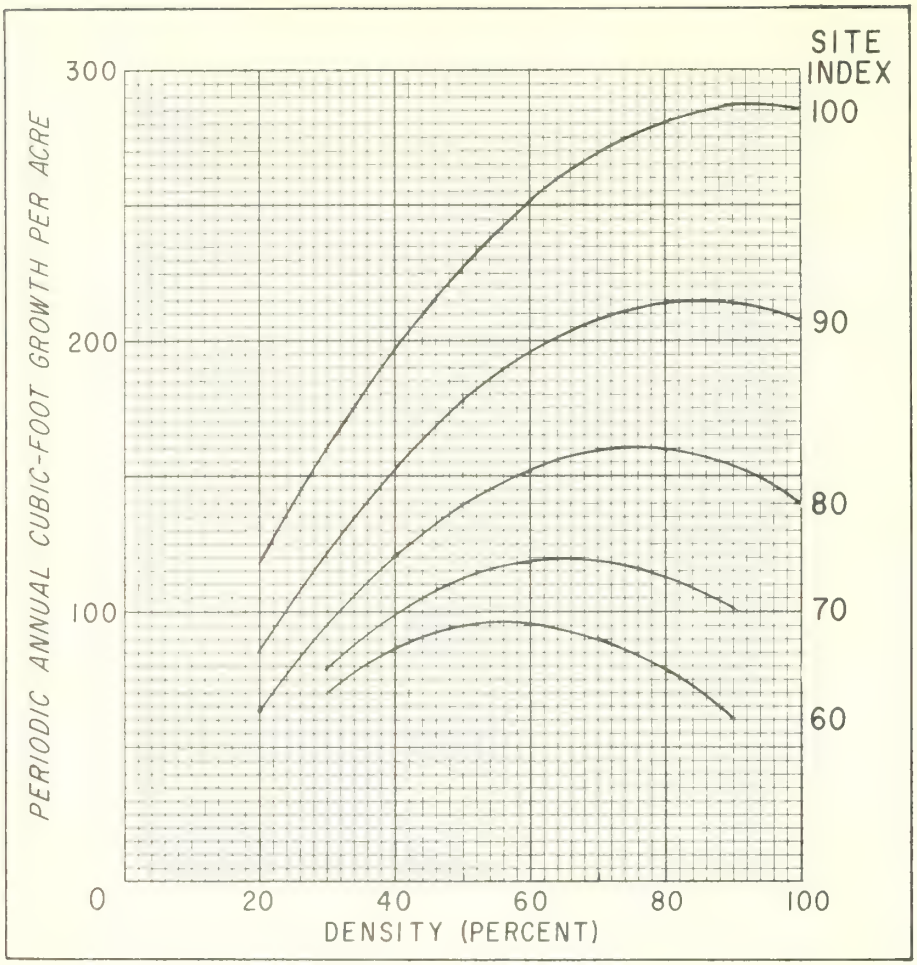

Figure 1. --Relation of periodic annual cubic-foot growth in thinned stands to age, site, and density percent at age 30.

We were also able to explain over 78 percent of the variation in annual cubic-foot growth using basal area per acre after thinning as an expression of stand density. The relationship of growth to site index, stand age, and basal area was as follows:

(Equation 2)

$$\text{Cubic-foot growth} = 148.85409 + 0.28630\left(\frac{10{,}000}{\text{Age}}\right) + 0.0358(\text{Basal Area} \times \text{Site}) - 0.012(\text{Basal Area})^2 - 6.79599(\text{Site}) + 0.04451(\text{Site})^2$$

Where basal area = basal area per acre of all stems 0.6 inch d. b. h. and larger after thinning at the beginning of the 5-year period.

The results are shown in table 5 and figure 2.

The similarity of these separate analyses is quite apparent. The curvilinearity of the site-density relationships to cubic-foot growth is clearly illustrated in figures 1 and 2. The effect of age is apparent in Equations 1 and 2.

Table 5. --Relation of periodic annual cubic-foot growth to age, site, and basal area, in thinned stands

SITE 60

Age	Square feet basal area per acre													
	30	40	50	60	70	80	90	100	110	120	130	140	150	160
	Cubic feet													
30	--	--	74	82	88	92	93	91	88					
40	--	--	50	59	64	68	69	68	64					
50	--	--	36	44	50	54	55	53	50					
60	--	--	27	35	41	44	45	44	40					
SITE 70														
30	--	68	82	94	103	110	115	117	117	114	110			
40	--	44	58	70	79	86	91	93	93	91	86			
50	--	30	44	56	65	72	77	79	79	76	71			
60	--	20	34	46	56	63	67	70	70	67	62			
SITE 80														
30	60	81	99	114	127	138	146	152	155	156	155			
40	37	57	75	90	103	114	122	128	131	132	131			
50	22	43	60	76	89	100	108	114	117	118	117			
60	13	33	51	66	80	90	98	104	108	109	107			
SITE 90														
30	79	103	124	143	160	174	186	195	202	207	209	209	206	201
40	55	79	100	119	136	150	162	172	179	183	185	185	183	178
50	41	65	86	105	122	136	148	157	164	169	171	171	168	163
60	31	55	77	96	112	127	138	148	155	159	162	161	159	154
SITE 100														
30	106	134	159	181	201	219	235	248	258	266	272	276	277	275
40	83	110	135	158	178	196	211	224	235	242	249	252	253	252
50	68	96	120	143	163	181	196	210	220	228	234	238	238	237
60	59	86	111	134	154	172	187	200	211	218	225	228	229	228

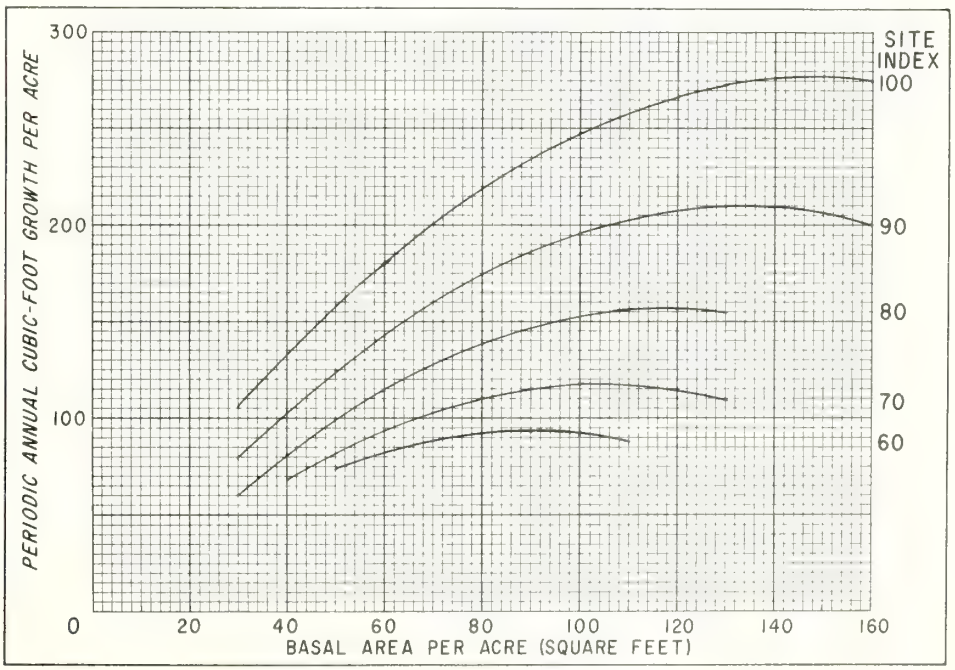

Figure 2. --Relation of periodic annual cubic-foot growth in thinned stands to age, site, and basal area at age 30.

Unthinned Stands

In the unthinned stands, the only measure of stand density used in relation to cubic-foot growth was density percent, because of success with this measure in past analyses. The relation of growth in cubic feet per acre to site index, stand age, and density percent in the unthinned stands was as follows:

(Equation 3)

$$\text{Cubic-foot growth} = -103.99189 + 0.31055\left(\frac{10{,}000}{\text{Age}}\right) - 0.02553(\text{Density Percent})^2 + 0.05158(\text{Site} \times \text{Density Percent})$$

Where density = percent of theoretical full stocking at the beginning of the 5-year period

The coefficient of determination for this expression was approximately 76 percent. The results are shown in table 6 and figure 3.

Although the coefficient of determination is not as high as the corresponding equation in thinned stands, similar curve shapes, a site-density interaction, significant effects of age and site, and culmination of growth at higher densities on high sites than on low sites are also apparent in the unthinned stands.

Table 6. --Relation of periodic annual cubic-foot growth to age, site, and density percent, in unthinned stands

Age	Density percent									
	20	30	40	50	60	70	80	90	100	110
	Cubic feet									
SITE 60										
30	51	69	82	90	93	91	84	71	54	
40	25	44	57	65	67	65	58	45	28	
50	10	28	41	49	52	50	42	30	12	
60	0	18	31	39	42	39	32	20	2	
SITE 70										
30	61	85	103	116	124	127	125	118	105	
40	36	59	77	90	98	101	99	92	79	
50	20	43	62	75	83	86	84	76	64	
60	10	33	51	65	73	76	73	66	54	
SITE 80										
30	72	100	124	142	155	163	166	164	157	
40	46	74	98	116	129	137	140	138	131	
50	30	59	82	101	114	122	125	123	115	
60	20	49	72	90	104	112	115	112	105	
SITE 90										
30	82	116	144	168	186	199	207	210	208	201
40	56	90	118	142	160	174	182	185	183	175
50	41	74	103	126	145	158	166	169	167	160
60	30	64	93	116	134	148	156	159	157	150
SITE 100										
30	92	131	165	194	217	235	249	257	260	258
40	67	105	139	168	191	210	223	231	234	232
50	51	90	124	152	176	194	207	216	219	217
60	41	80	113	142	165	184	197	205	208	206

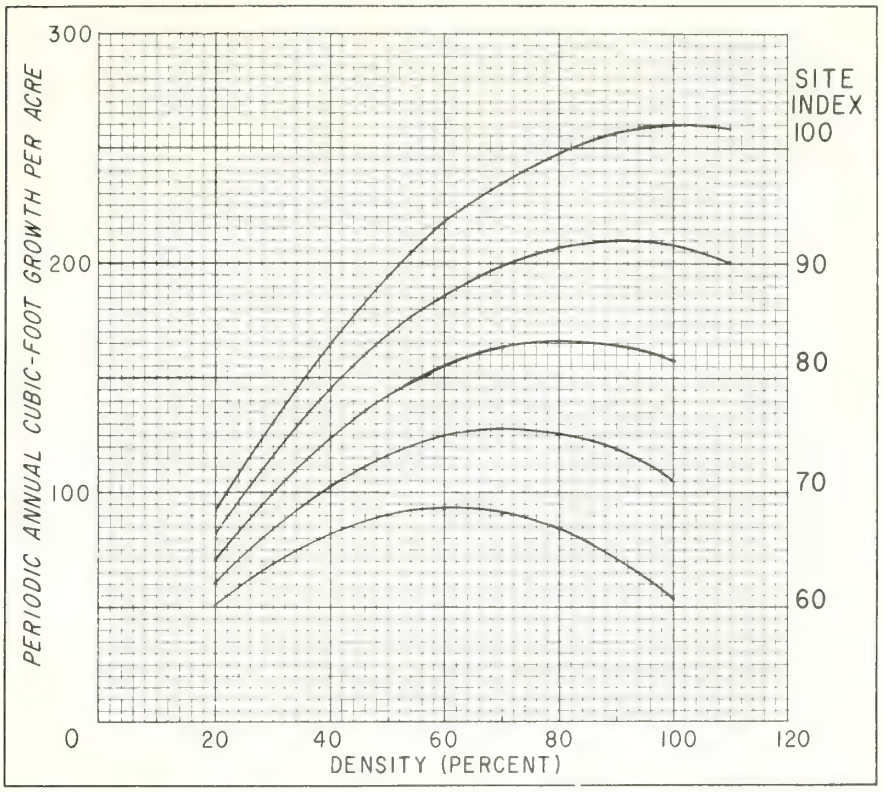

Figure 3. --Relation of periodic annual cubic-foot growth in unthinned stands to age, site, and density percent at age 30.

DISCUSSION

Wenger et al. (7) discussed the results of this study at the end of 5 growing seasons. They concluded that cubic-foot volume growth was significantly related to site index and residual density after thinning. Cubic-foot volume growth was also significantly related to age as well as site index and density of unthinned stands. However, no curves or optimum densities were apparent then and none of their equations accounted for more than 40 percent of the variation in growth.

The coefficients of determination obtained in this study during the second 5-year growth period (75 to 80 percent) are high enough to provide reasonable predicting accuracy. For example, the standard error of estimate for Equation 1 is ± 38 cubic feet at the mean. Some of the factors which perhaps account for the unexplained error include mortality, diameter distribution, less than full use of growing space for a short period following the heavier thinnings, genetic variation, clustering, climatic differences, and measurement error.

The tabular and graphic values presented in this paper have two principal uses for the practicing forester, as a prediction mechanism and as a prescription tool.

The forester using these tables as a prediction mechanism must develop a scale-down factor for his individual holdings before the growth predictions are meaningful. The growth predicting equations were developed under ideal natural conditions and approach the maximum growth values obtainable from natural loblolly pine under any given age, site, and stand density combination unless cultural measures are instigated which, in effect, change the site. The plots represented in these analyses are more uniform than can be expected in entire forest management units, clustering is minimized, and normal deterrents to growth that are present in forest units larger than $\frac{1}{4}$ acre were absent from the sources of these data.

The same characteristics which make scale-down necessary for growth predictions, however, enhance the value of the results for prescription purposes. They provide guides for forest management under conditions that approach the goal of most forest managers of loblolly pine; i.e., units of uniform site, condition classes and spacing in pure loblolly pine, vigorous stands, and disease- and insect-free stems. Thus the levels of age, site, and stocking at which growth changes occur closely approach absolute values that are logical goals and guides and are indeed meaningful in forest management planning.

The culmination of growth at low densities on low sites and high densities on high sites was expected. Gruschow and Evans (3) obtained similar curve shapes in their work in young slash pine stands, and McClay (4) had indications of the same relationship in partially cut 25- to 35-year-old loblolly pine.

The management implications of this conclusion are quite broad. They indicate that the forest manager should retain a higher basal area on good sites than on poor sites if his management goal is to produce maximum merchantable cubic-foot growth. For example, differentiating Equation 2 with respect to basal area indicates that merchantable cubic-foot growth culminates at a total basal area per acre stocking of approximately 90 square feet at Site Index 60 and at approximately 150 square feet per acre at Site Index 100.

The results of this study disagree with the European idea that growth does not reach an optimum within its natural limits of stocking (5). The current study shows culmination of the growth curves, although relatively flat curve forms result that indicate that a wide range of stocking can be maintained while still producing 90 percent of optimum growth.

The flat curve form over a wide range of stocking gives the forest manager an additional tool in forest regulations; it provides him with a sound basis to store volume on the stump and reduces disparities in operations occasioned by uneven distribution of age classes. It also indicates that he has a wider range of stocking levels than previously recommended which will produce near equal volumes of growth, thus giving him a choice of a wider range in alternative rates of return. With overlapping stocking levels at near optimum growth rates for successive site index classes, not much loss in growth can accrue because of relatively imprecise site classifications.

The growth levels of the thinned and unthinned stands show little or no difference at the same stocking level. Mathematically, there is no significant difference between comparable expressions. Biologically, on the good sites, there is an indication that thinning increases effective stocking and subsequently growth for a given stocking level, perhaps by elimination of moribund trees that add to the stocking level value but do not appreciably add growth. We interpret the similarity between growth in thinned and unthinned stands to indicate that there has been little shock effect and that the thinned stands have been able to regain full utilization of growing space with rapidity following thinning from below. Any reduction in growth during the 5-year period in the thinned stands was not greater than the reduction in the unthinned stands occasioned by limited mortality.

There was considerable similarity between the results of this study and the Hitchiti compartment study reported by Brender in "Growth predictions for natural stands of loblolly pine in the lower Piedmont" (1). The Hitchiti study also produced relatively flat curve forms.

The progressive culmination of growth at higher levels of stocking as site increases was evident in both studies. Stocking levels at growth culmination, however, were higher in the stand density study than in the Hitchiti study. Part of this difference can be explained by differences in the measurement of stocking levels; total basal area of stems 1.0 inch d. b. h. and larger entered the stocking value in this study, whereas only stems 5.6 inches d. b. h. and larger were present in the Hitchiti measure of stocking. Also, the smaller, uniform plot size in the stand density study minimized the effect of clustering within plots and eliminated much of the variation in site and density within plots--factors not linear in their expression.

SUMMARY

A series of 153 plots were selected in 20- to 60-year-old stands of natural loblolly pine of a wide range in site index and density in Georgia, South Carolina, and Virginia. Approximately one-third of these plots were thinned to a range of residual densities at the time of plot establishment. These plots were rethinned and another one-third received their first thinning at the end of the first 5-year growth period. This paper discusses the results of analyses of the 5- to 10-year cubic-foot volume growth.

In the thinned stands, cubic-foot volume growth was found to be significantly related to age, site, and density expressed as density percent and total basal area per acre:

(Equation 1)

$$\text{Cubic-foot growth} = 205.0 + 0.26005\left(\frac{10{,}000}{\text{Age}}\right) - 0.03087(\text{Density Percent})^2$$

$$+ 0.05824(\text{Site} \times \text{Density Percent}) - 8.11990(\text{Site}) + 0.05328(\text{Site})^2$$

$$R^2 = 0.781$$

(Equation 2)

$$\text{Cubic-foot growth} = 148.85409 + 0.28630\left(\frac{10{,}000}{\text{Age}}\right) + 0.0358(\text{Basal Area} \times \text{Site}) - 0.012(\text{Basal Area})^2 - 6.79599(\text{Site}) + 0.04451(\text{Site})^2$$

$$R^2 = 0.781$$

In the unthinned stands, cubic-foot growth was related to age, site, and density percent in the following formula:

(Equation 3)

$$\text{Cubic-foot growth} = -103.99189 + 0.31055\left(\frac{10{,}000}{\text{Age}}\right) - 0.02553(\text{Density Percent})^2 + 0.05158(\text{Site} \times \text{Density Percent})$$

$$R^2 = 0.761$$

A progressive culmination of growth at higher levels of stocking as site increases is evident in all three expressions. The relatively flat growth curves in relation to density with a culmination point show that the forest manager has a wide range of stocking levels available without appreciable loss in merchantable cubic-foot growth.

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Agriculture Asheville

Station Paper No. 128 August 1961

SOUTHERN PINE BEETLE

A Review of Present Knowledge

by

John C. Dixon and E. A. Osgood

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SOUTHERN PINE BEETLE

A Review of Present Knowledge

by

John C. Dixon and E.A. Osgood

The southern pine beetle, Dendroctonus frontalis Zimm., is one of the most destructive insects of pine in the South and has been recognized as such since investigations by Hopkins (1899). Outbreaks of this native insect have occurred at irregular intervals since the 1890's. Most reports indicate only the general area affected by outbreaks; others indicate the size in acres or square miles (Hopkins, 1903; Craighead, 1925; St. George, 1930; Cary, 1932; Hetrick, 1941; Southern Forest Experiment Station, 1957, 1959). Estimates of losses from individual outbreaks range from 1,200 MBF to 200,000 MBF (Anonymous, 1924; Lee, 1954b; Southern Forest Experiment Station, 1955a, 1955b, 1958). In an outbreak in the Southeast from 1952-1955 an estimated 53,200 MBF of sawtimber plus 138,600 cords of poletimber were lost (Merkel and Kowal, 1956). Blue stain introduced by the beetle degrades the wood and causes additional economic losses even when dead trees can be salvaged. Furthermore, the dead pines which cannot be salvaged create a fire hazard and are usually replaced by slow growing, undesirable hardwoods. In most cases stands become less productive and decline in commercial value.

Although this insect has been studied rather intensively and its general life history is known, its behavior and relationship to the environment and the factors contributing to epidemics are poorly understood. Outbreaks frequently occur without apparent warning, yet populations may disappear as quickly as they appeared. Research is needed to determine the factors contributing to the rise and decline of populations. The present review attempts to bring together pertinent data as an aid to future research.

DISTRIBUTION

The range of the southern pine beetle extends from southern Pennsylvania to southern Missouri, south to the Gulf and east to the Atlantic seaboard. It occurs in extensive areas of eastern Oklahoma and Texas (Chamberlin, 1939). Hopkins (1899, 1909a) recorded it from the District of Columbia, Pennsylvania, Maryland, Virginia, West Virginia, North Carolina, South Carolina, Tennessee, Georgia, Florida, Alabama, Mississippi, Louisiana, Arkansas, Oklahoma, and Texas. Specimens have also been collected from southeastern Kentucky by personnel of the Southeastern Forest Experiment Station. St. George and Beal (1929) reported that outbreaks occurred periodically in Delaware and that the beetle was known to occur in the southernmost portions of New Jersey, Ohio, Indiana, Illinois, and Missouri (fig. 1).

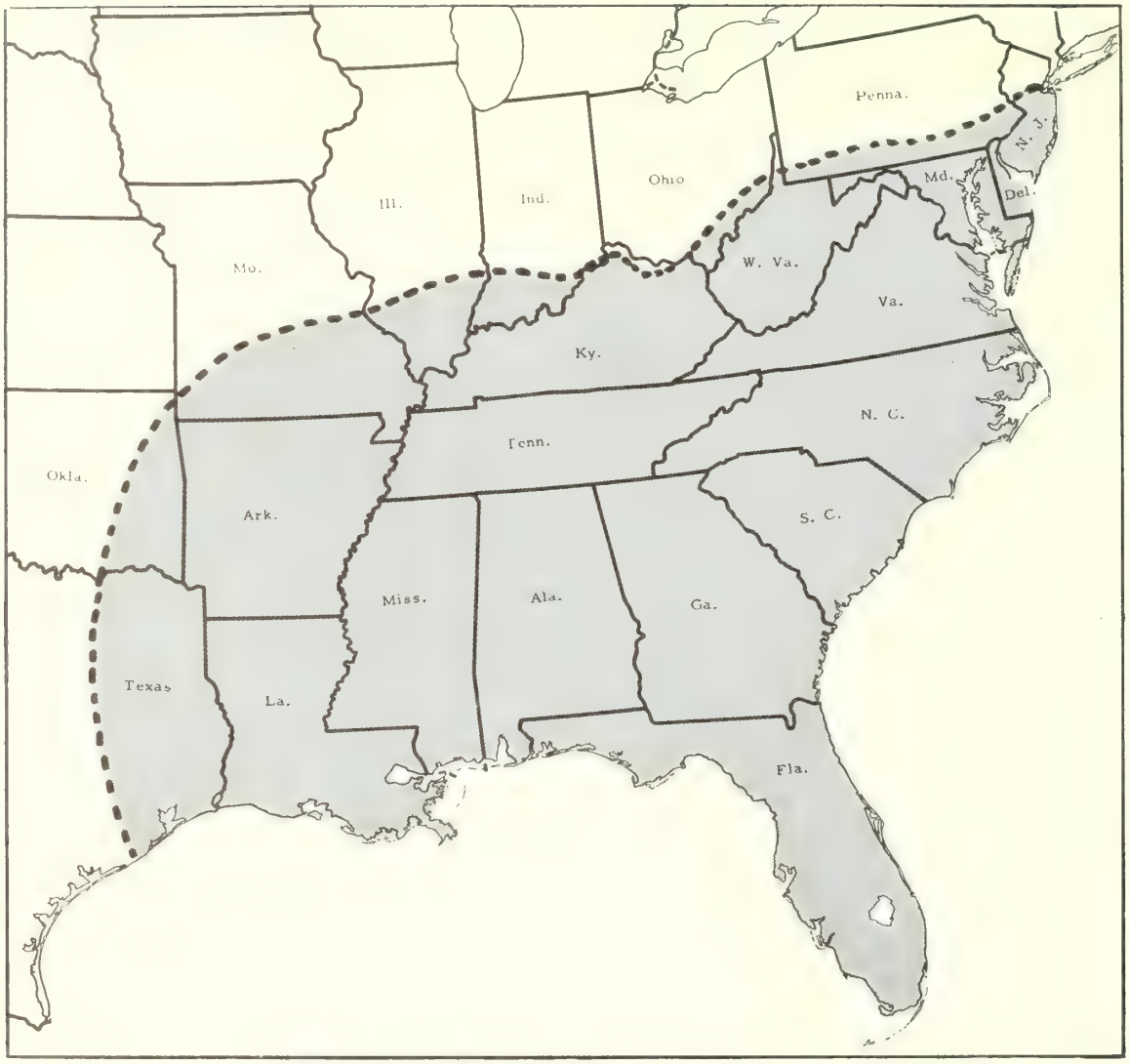

Figure 1.--Distribution of the southern pine beetle in the United States.

HOSTS

St. George and Beal (1929) reported that the southern pine beetle attacked and killed pines of all species occurring within its range, and that it was especially destructive to loblolly and shortleaf pines. The following hosts were recorded by Hopkins (1909a): shortleaf pine, Pinus echinata Mill.; pitch pine, P. rigida Mill.; loblolly pine, P. taeda L.; Virginia pine, P. virginiana Mill.; Table-Mountain pine, P. pungens Lamb.; eastern white pine, P. strobus L.; longleaf pine, P. palustris Mill.; spruce pine, P. glabra Walt.; red spruce, Picea rubens Sarg.; and Norway spruce, P. abies (L.) Karst. Wyman (1924) recorded slash pine, P. elliottii Engelm., as being attacked. Personnel of the Southeastern Station have also observed the beetle killing Japanese red pine, P. densiflora Sieb. and Zucc., and red pine, P. resinosa Ait., in plantations in western North Carolina and pond pine, P. serotina Michx., on the coast of North Carolina.

DESCRIPTION OF STAGES

The southern pine beetle was originally described by Zimmerman (1868). The description that follows is intended only to acquaint the reader with the general appearance of the insect in its different stages; most taxonomic details have been omitted. A number of authors have presented detailed descriptions of its life stages (Hopkins, 1899, 1909a; Blackman, 1922; Chamberlin, 1939; and Fronk, 1947).

The adult southern pine beetle is a slender, cylindrical insect, 2.2 to 4.2 mm. long, brown to black in color. The front of the head has a longitudinal groove with elevations on each side. The elytral declivity is convex. The female may be distinguished from the male by the presence of a transverse elevation on the anterior portion of the pronotum (Blatchley and Leng, 1916).

The egg is oblong to oval, pearly white in color, 1.5 mm. long and 1 mm. wide. Upon emerging, the small, wrinkled, legless, grublike larva is approximately 2 mm. long. Its head capsule is reddish brown. The full grown larva is approximately 5 mm. long. Head capsule measurements indicate that there are four larval instars (Fronk, 1947). The mature larva migrates to the outer bark and constructs a pupal cell in which it transforms to the pupal stage. The white fragile pupa is 3 to 4.2 mm. in length and is distinguished by its large head and prothorax which closely resemble those of the adult. The pupa molts to a soft, whitish adult beetle which soon hardens and changes in color to a reddish brown and then to a dark brown or black.

BIOLOGY AND ECOLOGY

Life History

The details of the life history of the southern pine beetle were originally reported by Hopkins (1899, 1909b). The number of generations of the beetle per year varies principally with climatic conditions and they are difficult to follow because of their complex overlapping and because attacks appear to be continuous during favorable weather. Hopkins (1899, 1909b) found there were two to three complete generations in West Virginia; there may be four or a partial fifth generation at the lower elevations and more southern localities of that area. Other studies conducted in North Carolina and Virginia resulted in similar findings (Fronk, 1947; St. George and Beal, 1929).[1/2/3/] The number of generations that occur in the southern part of the beetle's range is not definitely known (fig. 2).

1/ Beal, J. A., and St. George, R. A. Progress report on the southern pine beetle. Summary of observations and experiments. U. S. Bur. Ent. Plant Quar., Div. Forest Insect Invest., Asheville, N. C. 1926. (Typewritten, 35 pp.)

2/ Craighead, F. C., and St. George, R. A. Progress report on forest insect investigations conducted at Asheville, N. C., April to October, 1925. U. S. Bur. Ent. Plant Quar., Div. Forest Insect Invest., Asheville, N. C. 1925. (Typewritten, 40 pp.)

3/ MacAndrews, A. H. The biology of the southern pine beetle. Syracuse University. 1926. (Unpublished thesis, 103 pp.)

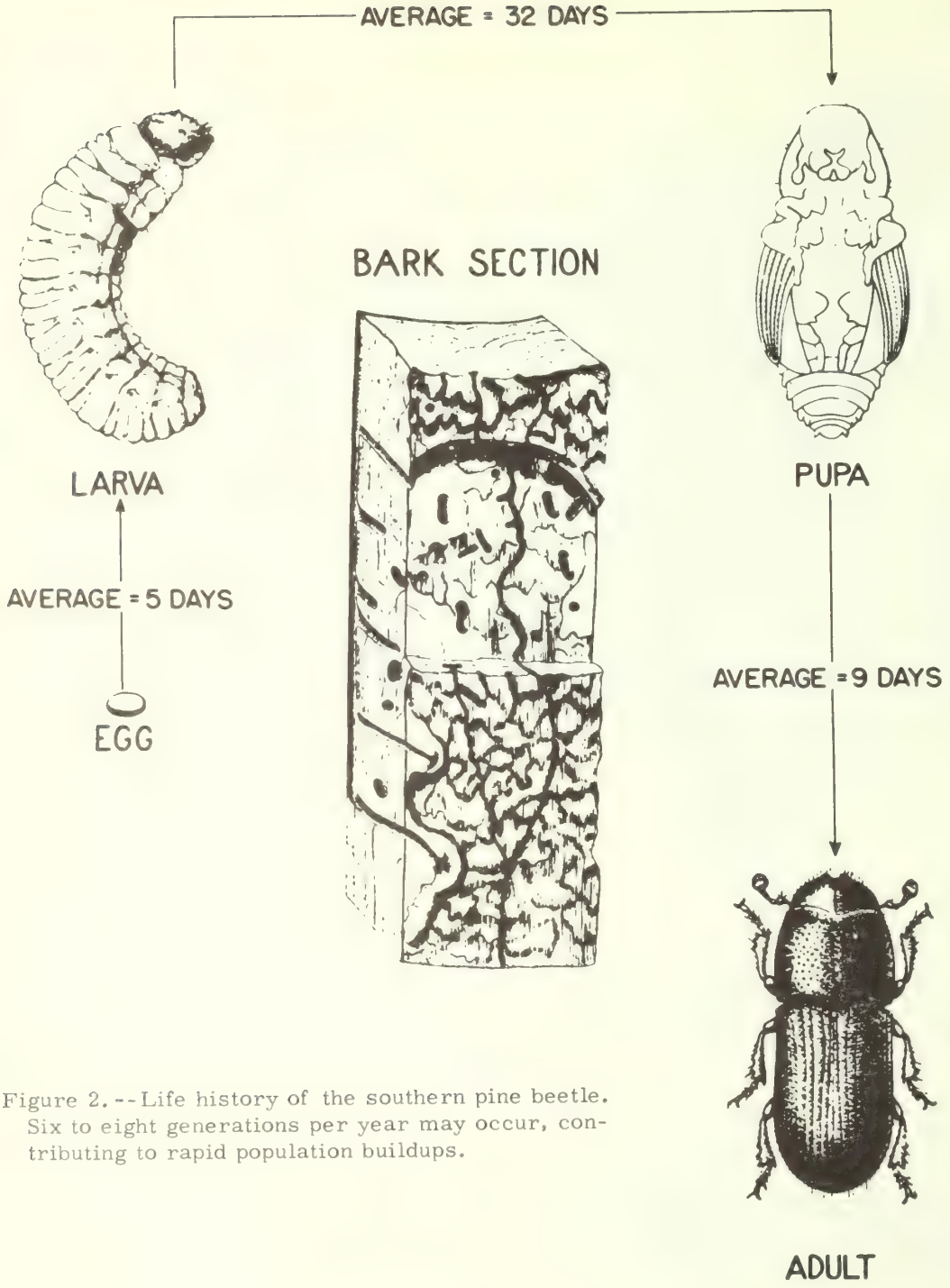

Figure 2.--Life history of the southern pine beetle. Six to eight generations per year may occur, contributing to rapid population buildups.

The beetle passes the winter in all stages of development, and emergence varies with the overwintering stage and climatic conditions. In the southern Appalachians the more mature individuals emerge about the middle of April; the remaining stages may continue to emerge through the greater part of June (fig. 3).

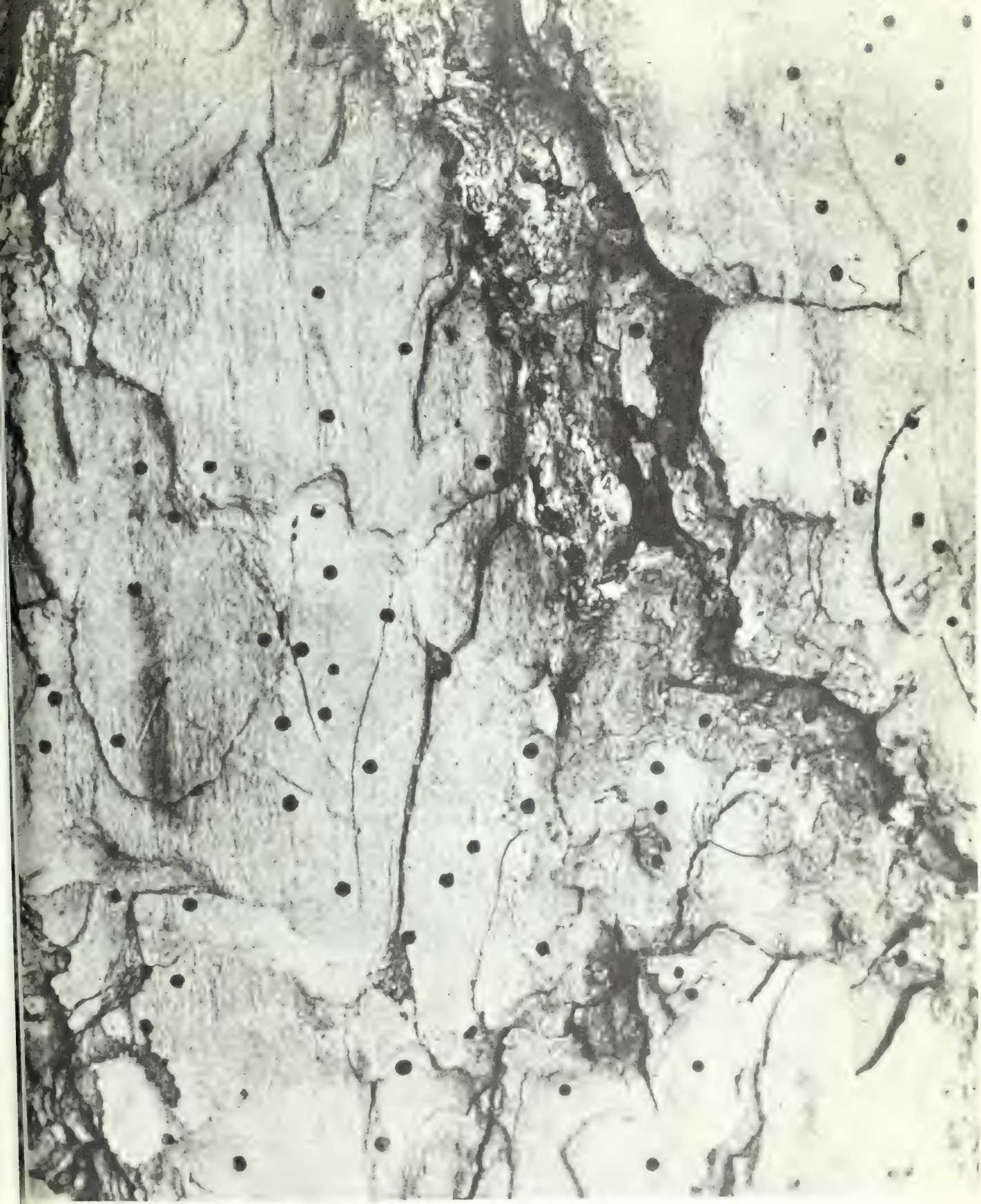

Figure 3.--Emergence holes of the southern pine beetle in the bark of pine.

MacAndrews (see footnote 3) stated that the "old parent adults emerge a week to ten days or more before their offspring. They usually leave the tree when the broods are in the larval stages.... While some of the adults emerge at once, others may construct a short feeding gallery, away from the pupal cell, before finally emerging." Each adult makes its own exit hole.

Emerging adults of most generations exhibit no set pattern of attack; they may attack nearby uninfested trees or migrate a considerable distance from the trees in which they developed. Hopkins (1899) reported that upon emergence in the spring, hibernating beetles "...evidently do not attack the healthy, living trees, but excavate their brood galleries in the living bark of trees injured but not killed by the attack of late broods the previous fall." Generally they attack the middle and upper trunk first; as attacks progress they may extend to within five feet or less of the ground. Trees from the smaller diameters to the largest are attacked and killed. In "hot spots" and areas where preferred material is scarce, trees as small as three-quarters of an inch d.b.h. have been killed.

When initial attacks occur on apparently healthy pine trees, a profuse flow of sap usually takes place at the point of entry. The adults not "pitched out" extend the gallery laterally through the outer and middle layers of bark for some distance (one or two inches) before the inner layer is penetrated (Hopkins, 1899). If the flow of sap is moderate, the beetles bore directly to the wood and construct their galleries through the inner bark. MacAndrews (see footnote 3) reported that "the female bores directly into the cambium and at once constructs a small nuptial chamber." This chamber is approximately 5 mm. long and 3 mm. wide. The beetles are monogamous and usually only one male and one female are found in each gallery. After fertilization the female begins construction of the winding S-shaped gallery. Galleries vary in length from 2 to 12 inches (fig. 4). Craighead and St. George (see footnote 2) observed that parent adults extended the egg galleries about an inch a day. Eggs are laid singly in niches at irregular intervals along the sides of the galleries. Fronk (1947) reported the average time for hatching as 5.5 days. MacAndrews (see footnote 3) stated that: "Some of the beetles expended their energy in laying eggs and constructed short galleries. Others concentrated on gallery construction and laid comparatively few eggs. The daily rate of [gallery] growth also varies with the condition of the cambium. When a copious flow of resin was present, the gallery construction slowed up considerably."

The larvae mine away from the egg gallery at right angles and their galleries are often concealed by the phloem. The larval gallery is usually short and narrow; at the end is an oval-shaped feeding area which is later extended into the dry outer bark where pupal cells are constructed. Larval mines vary from 5 to 20 mm. in length, with the average being 10 mm.[4/] If the bark dries too rapidly, the larvae will continue to bore for some distance through the inner portion of the bark without increasing in size (Holst, 1937; Hopkins, 1909a). Fronk (1947) reported that there were four larval

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4/ Lee, R. E. A study of the southern pine beetle in epidemic status. U. S. Forest Serv. South. Forest Expt. Sta. 1955. (Office Rpt., 13 pp.)

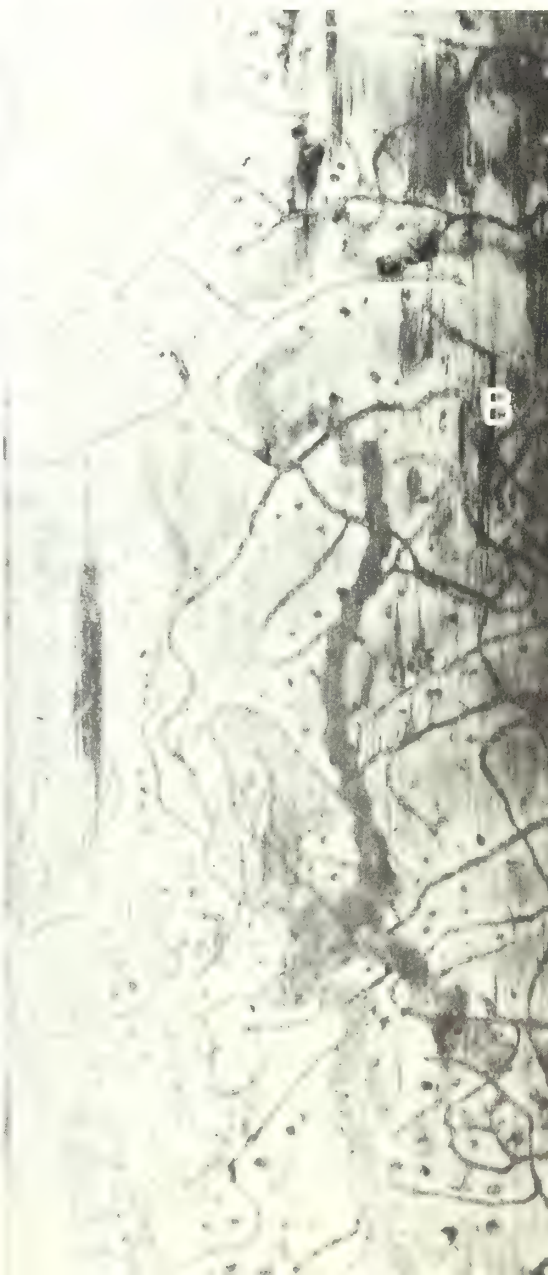

Figure 4.--A, S-shaped adult galleries and small larval galleries in the inner bark of pine. B, Southern pine beetle galleries etched on the surface of wood of pitch pine. The large galleries packed with boring dust are those of a wood borer, Monochamus sp.

instars and that on the average 32 days were spent in the larval stage. He found the average pupal period to be 9.4 days and the average time from egg to adult to be 47 days with a minimum of 40 and a maximum of 54 days. Other workers have reported similar results (Hopkins, 1899; see also footnote 3). St. George and Beal (1929) found that under favorable conditions a brood can develop from egg to adult in 30 to 40 days.

The southern pine beetle has a great potential for increase from generation to generation and from season to season. On the basis of averages of counts of beetles attacking per square foot and beetles emerging per square foot, MacAndrews (see footnote 3) reported an increase of 800 percent. Craighead et al. (1927) reported an average potential increase of 850 percent and that an increase of 1,000 percent may well be possible. Emergence was reduced in small, thin-barked trees (see footnotes 2 and 3). The tremendous capacity of the beetle to multiply explains why sudden changes from endemic to epidemic populations may occur when conditions become favorable for the insect. Just what these conditions are and how they influence the biology of the beetle in its relationship to the environment is not known.

Characteristics of attack.--Characteristics of injury to trees and changes in foliage following attack have been reported by several authors (Hopkins, 1899, 1909b; St. George and Beal, 1929; see also footnotes 2 and 3). The first external evidences of attack are the presence of pitch tubes on the middle to upper trunks and reddish boring dust along the upper trunks and in loose bark at the bases of the trees. If attack is sufficient to kill trees, a series of changes take place in the foliage as the attack progresses. During the summer, about two weeks after attack, the needles appear faded and yellowish; in about a month they appear sorrel to reddish brown; and in another month the foliage is shed (fig. 5). By the time the needles are reddish brown, all bark except at the base of the tree is dead, but the base of the tree may remain alive for weeks or months after the top is dead. Craighead and St. George (see footnote 2) stated that the yellow to sorrel stage of the needles coincided with the emergence of the brood. By the time the needles are reddish brown, practically all the broods have emerged (Hopkins, 1909b). MacAndrews (see footnote 3) found that the old needles at the base of the crown were the first to change color, followed in succession by the old needles at the top of the crown, the new needles at the base, and the new needles at the top. When the bark is removed, the S-shaped galleries of the beetle can be seen on the inner bark and outer surface of the wood (Hopkins, 1909b; St. George and Beal, 1929).

The rapid dying of attacked trees is associated with penetration of blue stain, Ceratocystis minor Hedgc., introduced by beetles. The tree dries out quickly, phloem is destroyed, and the foliage begins to fade in about three weeks. In the absence of blue stain, mortality may be delayed considerably. Craighead and St. George (1940) noted that a group of shortleaf pines attacked in the fall showed no indication of fading until the following spring. In this case relatively few beetles reached the xylem and interference with conduction by the fungus was delayed. As a result the affected trees were able to survive over the winter and did not fade until spring.

Figure 5.--A large stand of pine killed by the southern pine beetle in Tennessee. A few live pines are scattered through this once dense stand.

Phenological observations by St. George and Beal (1929) indicated that the more mature beetles began to emerge in the spring about the time eastern redbud, Cercis canadensis L., bloomed and that later ones continued to emerge until midsummer when the blackberries began to ripen. MacAndrews (see footnote 3) correlated the emergence of the first generation with the blossoming of the flame-colored azalea, Rhododendron calendulaceum (Michx.) Torr.; the second with the blossoming of mountain-laurel, Kalmia latifolia L.; and emergence of the third generation with blossoming of sourwood, Oxydendrum arboreum (L.) DC.

Flight habits.--Little intensive research has been done on the flight habits of the southern pine beetle, and there are many conflicting observations and opinions on the subject. A great deal of research is needed on flight behavior in relation to migration and attack of trees. Hopkins (1899, 1909b) believed that, since southern pine beetles were found in electric light globes and were otherwise attracted to light, the species flew at night as well as during the day. In contrast, MacAndrews (see footnote 3) failed to attract beetles to a lamp in an epidemic area even though many other species of bark beetles and cerambycids were attracted.

Upon emergence beetles fly to other living trees or sometimes to freshly cut logs (St. George and Beal, 1929). Balch[5/] noted that upon emergence beetles flew above the trees toward light, and that when in the open their direction seemed to be determined by the direction of the wind. Hopkins (1899) reported that from the character of attack at certain times it appeared that great migrating swarms occurred which ascended high into the air and were evidently carried long distances by strong winds and storms. This was indicated by the fact that the first groups of trees that died in a newly invaded locality were usually on high slopes where the swarm would come into contact with the timber. At the conclusion of such flights great numbers of beetles were observed to congregate under the loose bark flakes of healthy trees before simultaneous entrance into the inner bark (Hopkins, 1909b).

A peculiar habit of the beetle is that of migrating from one group of brood trees to another group of trees some distance away, instead of continuing their attack on the trees immediately surrounding those from which they emerge (Hopkins, 1899).

Speers (1956) used radioisotopes in an attempt to learn more about the flight habits of the beetle. Improvement of new techniques such as this may be profitable in studies of migration and dispersal of insects.

Beetle breeding in felled logs and weakened trees.--Hopkins (1909b) stated that the southern pine beetle would breed in injured and felled trees, but specific instances of such attacks were not cited. The first report of the beetle successfully completing a generation in felled logs was made by MacAndrews (see footnote 3). Craighead and St. George (see footnote 2) also observed the beetle attacking felled logs. St. George and Beal[6/] reported that when occurring in small numbers the beetle is found breeding in weakened and dying trees. The beetle is also associated with secondary species of insects and will attack recently felled logs and slash down to a diameter limit of about four inches, preferring the sides and bottoms of such material. They also reported that the beetle was capable of building up to epidemic proportions in felled logs and slash in a single season after being reduced to a minimum by low winter temperatures.

However, Craighead et al. (1927) summed up the early findings on the importance of such material in causing outbreaks by saying that "...the infrequency with which the southern pine beetle attacks slash, cull logs, or wind-blown trees immediately eliminates it as an argument for the disposal of such material." Later, St. George and Huckenpahler[7/] visited many areas where summer-cutting had been carried out, and in only one case was an attack attributed to population buildup in cuttings. These observations indi-

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5/ Balch, R. E. The influence of the southern pine beetle on forest composition in western North Carolina. Syracuse University. 1928. (Unpublished thesis, 33 pp.)

6/ St. George, R. A., and Beal, J. A. Progress report on studies on the southern pine beetle (Dendroctonus frontalis Zimm.). U. S. Bur. Ent. Plant Quar., Div. Forest Insect Invest., Asheville, N. C. 1927. (Typewritten, 40 pp.)

7/ St. George, R. A., and Huckenpahler, B. J. Insects in relation to cutting of pines in emergency conservation work in the southeastern United States. U. S. Bur. Ent. Plant Quar., Div. Forest Insect Invest., Asheville, N. C. 1934. (Typewritten, 14 pp.)

cate that the danger of attracting the southern pine beetle by cutting pines in midsummer is not as great as formerly believed.

Although the beetle will occasionally attack felled logs and slash, these materials apparently do not play an important role in the epidemiology of the insect.

Factors Predisposing Stands to Attack

Many factors may predispose trees and stands to attack by the southern pine beetle and contribute to the development of epidemics. Such factors as drought, rainfall deficiencies, rainfall excesses, fire, lightning, or mechanical injury to trees are complex in themselves and in their interrelationships, and their individual effects in relation to beetle outbreaks cannot be readily separated.

Drought and rainfall deficiencies.--Drought and rainfall deficiencies have long been recognized as factors contributing to outbreaks of the southern pine beetle (Wyman, 1924; Craighead, 1925; St. George, 1930, 1931; Knull, 1934; Hetrick, 1949; and Merkel, 1956; see also footnotes 2, 3, 4, and 8). Craighead and St. George (footnote 2) indicated that drought played an important part in inducing attack and that changes in trees as a result of drought also affected brood development. Knull (1934) stated that drought weakened trees and made them more susceptible to attack. After comparing southern pine beetle outbreaks, Lee (footnote 4) reported: "Mounting evidence indicates that when the beetle is on the incline, the most susceptible hosts are drought-weakened pines, and it is suggested that these trees may even be on soils so depleted of moisture that the permanent wilting point has been reached."

Wyman (1924) observed deficiencies in rainfall preceding an outbreak that was subsequently curtailed by excesses in precipitation. St. George and Beal (footnote 8) considered deficiencies in rainfall during July and August of one inch or more as contributing to outbreaks. They stated that under such conditions the trees were in a weakened condition and easily overcome by the beetles.

After comparing outbreaks with precipitation records, Craighead (1925) concluded, that with two exceptions, every southern pine beetle outbreak on record occurred during periods of rainfall deficiency. This suggested an intimate relationship between epidemics and drought periods. He felt that late summer and fall deficiencies were more important in producing outbreaks than those in other seasons. In contrast to this, Merkel (1956) stated that there was not sufficient evidence to show that droughts in late summer and early fall were more conducive to outbreaks than rainfall deficiencies at other times of the year. Further, "...close analysis of weather data indicates that winter, spring, and early summer droughts, or accumulated precipitation deficiencies early in the growing season, contribute to the development of outbreaks, which may not show up until late summer or fall."

8/ St. George, R. A., and Beal, J. A. Report on the southern pine beetle outbreak located at Hot Springs, N. C., and vicinity. U. S. Bur. Ent. Plant Quar., Div. Forest Insect Invest., Asheville, N. C. 1929. (Typewritten, 8 pp.)

The collapse of outbreaks has often been associated with excesses of rainfall (Wyman, 1924; Craighead, 1925). Craighead stated that "...heavy precipitation during periods of attack and brood development seems to be most effective in control by killing the beetles and young larvae beneath the bark of attacked trees." On the other hand, Hetrick (1949) reported: "Excess of precipitation as well as deficiencies of rainfall may contribute to outbreaks of the southern pine beetle. Damage to root systems of pine trees contributes more attractiveness to bark beetles than damage to trunks of trees."

As indicated, there appears to be no doubt that drought is associated with outbreaks of the southern pine beetle. Rainfall deficiencies have been noted preceding most outbreaks. It appears that winter, spring, and early summer deficiencies may be just as important as late summer and early fall deficiencies. Other factors may also be involved, however, because outbreaks have been known to collapse while favorable drought conditions have persisted. Some outbreaks have also occurred in the absence of droughts--even after periods of excess rainfall--and it is possible that copious and prolonged rainfall may damage root systems of trees and thus create favorable conditions.

Fire and lightning.--Observations indicate that fires have a direct influence in inducing beetle attacks (St. George and Beal, 1929). Knull (1934) observed that trees suffering from the ravages of fire and lightning appeared to suffer severely and seemed to be responsible for isolated infestations. The significance of the attack by the beetle in fire-killed timber is often more difficult to determine than for some other insects (St. George, 1928). Beal and St. George (see footnote 1) found it difficult to assess the influence of the beetle in the case of fire-damaged trees because mortality was due in part to the weakened condition of the trees. They concluded that fire was probably a much more important factor than insects in the removal of trees from the stand.

Craighead and St. George (1928) reported the southern pine beetle concentrating on a burned area apparently as a result of fire. Ips beetles, ambrosia beetles, and pine sawyers were also present, but only the southern pine beetle played an important part in tree killing. Most trees were killed as a result of fire and attack, not by insect attack alone; however, in practically all cases, mortality to trees five inches in diameter and over (trees also classed as dominants) was from the work of the southern pine beetle alone.

A heavy attack by the beetle was noted in standing pines whose tops had been completely burned off. Brood mortality was high and was attributed to increased water content of the stem because of complete defoliation. St. George and Beal (see footnote 6) concluded that severely burned trees which have lost their foliage do not furnish an ideal breeding site for the southern pine beetle, but instead serve as a check on its development. This condition should not be confused with conditions existing on less severely burned trees which have retained their foliage. Such trees were observed to contain heavy broods.

Most researchers who have worked with the beetle in the field have observed it attacking lightning-struck pine trees (fig. 6), but the exact nature of the attraction is unknown. Wind-thrown and lightning-struck trees have appeared to act as attractants in drought-affected areas, and in one instance 21 trees struck by lightning were subsequently attacked by the southern pine beetle (St. George, 1930). From 2 to 10 surrounding pines were also attacked and killed as a result of the attraction. St. George and Beal (see footnote 8) observed a large lightning-struck pine in the center of an infested area. The tree was heavily attacked and appeared to serve as a focal point for the start of the infestation.

Susceptibility of Individual Trees

Phloem moisture content.--Beal and St. George (see footnote 1) studied normal and drought-affected trees in order to detect differences in moisture relations. They found that the moisture content of the wood and phloem at all levels of the trunk and of the leaves was less in drought trees than check

Figure 6.--Lightning struck trees are attractive to beetles and may serve as foci for the initiation of southern pine beetle infestations.

trees. Moisture content is also altered by beetle attack. Following attack, the wood dries rapidly and an increase in moisture occurs at the base of the tree. "The wood of normal trees shows an increasing percentage from base to top. A gradual change to reverse condition begins after attack. This reversal is due to a more rapid drying out at the top and a delayed increasing water content at the base."

Several workers have pruned, topped, and watered trees in attempts to discover the effects of increased phloem moisture content on brood development (see footnotes 1, 2, 3, and 6). Although the results have varied greatly, brood emergence has been reduced in many cases. Transpiration reduction caused by pruning and topping probably accounts for the maintenance of phloem moisture content in such trees (see footnote 3). St. George (1931) observed that an abnormally moist condition of the inner bark, probably caused by lessened transpiration during the winter, may have been responsible for the death of the overwintering brood. St. George and Beal (see footnote 6) reported that artificial watering did not result in a direct reduction of the brood, but it appeared to prevent attack on some trees and reduced the brood in the basal portions of others.

It would appear that the moisture content of the bark and phloem, especially the phloem, is a critical factor which affects the survival of broods of the southern pine beetle. The phloem moisture conditions are also modified by the attacks of the beetles themselves. The subject of moisture content in trees, as associated with beetle outbreaks, must be studied intensely in the effort to determine the reasons for the rise and fall of beetle populations and the occurrence of epidemics.

Forest Composition and Stand Susceptibility

Balch (see footnote 5) studied the influence of the southern pine beetle on forest composition and found that in destroying thrifty stands of pure pine the beetle brought about replacement by mixed stands consisting largely of less valuable, slower growing species. The composition of future stands was predicted from estimates of advance reproduction. Such stands, it was thought, would consist of two age classes. The upper story would be composed of scattered pine and oak and the lower story would consist of 30 percent pine, 12 percent desirable hardwoods, and 58 percent undesirable hardwoods. The only possible advantage of such types of stands is that they would be fairly immune to southern pine beetle attacks.

Hoffman and Anderson (1945) found that pure pine stands were more susceptible to attack than mixed pine-hardwood stands. The openings resulting from bark beetle attacks did not revert to pure pine but were taken over by mixed pine-hardwood stands. The pines in such stands were those which had not succumbed to beetle attack. Little pine reproduction became established after the larger trees had died. On small areas better than three-quarters of the pine six inches d.b.h. and over were attacked and killed; the smaller trees were less subject to attack (fig. 7).

Figure 7.--Pine stand killed by the southern pine beetle showing advance pine and hardwood reproduction that will replace this formerly pure pine stand.

Lee (see footnote 4) compared southern pine beetle outbreaks in several states to determine whether similarities or differences in the environments might be found which could be used as indications of host susceptibility. The beetle was found to attack pines under a wide variety of conditions and did best in dense stands. There was great variation in the age and size of trees attacked; young, apparently thrifty stands were by no means immune. Osgood[9/] studied site and stand characteristics in many infested areas of the southern Appalachians. The beetle attacked pure stands growing under average field conditions. Based upon the factors measured, most pine stands found in this area were in poor condition.

Rearing Methods and Attempts to Induce Attack

As previously indicated, the southern pine beetle is characterized by violent fluctuations in populations. In order to conduct controlled biological and ecological studies, it is necessary to have a continuous supply of the beetles available. It has been impossible to conduct such studies because no satisfactory method for rearing the beetles has been found. Attempts to rear large numbers of beetles by inducing attack on standing trees and caged logs have produced varying results that have not been consistently successful.

Beal and St. George (see footnote 2) were unsuccessful in inducing attacks "...until the bark containing the beetles was caged with the material on which attack was desired." Several attacks were induced by this method on caged logs and in a standing tree, and further experiments conducted the following year (St. George and Beal, 1929) were so successful that it was assumed attacks could be induced whenever desired; however, no additional experiments were conducted. Caird (1935) was able to induce attacks on standing trees by similar methods. Attacks also occurred on trees adjacent to an infested caged bolt (fig. 8).

Recent efforts to rear the beetle under artificial conditions have met with little success. The application of electrical shock to bolts and the introduction of blue stain fungi before exposure to attack were unsuccessful.[10/] Osgood and Carter[11/] tried the following treatments with little success: (1) mechanical injury to standing trees; (2) caging infested bark on standing trees; (3) caging infested bolts on trees; (4) caging infested bark and phloem with uninfested bolts (ends waxed); (5) caging infested bark and phloem with uninfested scorched bolts; (6) caging infested bark and phloem with uninfested mechanically injured bolts; (7) caging infested bark and phloem with uninfested bolts treated with sulfuric or acetic acid; and (8) caging infested bark on uninfested bolts. It appeared that the high moisture contents of the wood and inner bark of bolts were unfavorable for the development of the early larval stages.

9/ Osgood, E. A. A study of site and stand characteristics of southern pine beetle infestations. U. S. Forest Serv. Southeast. Forest Expt. Sta. 1958. (Office Rpt., 5 pp.)

10/ Smith, V. K., Jr. Techniques used in attempts to rear Dendroctonus frontalis. U. S. Forest Serv. South. Forest Expt. Sta. 1954. (Typewritten, 18 pp.)

11/ Osgood, E. A., and Carter, W. A. Techniques used in preliminary attempts to rear southern pine beetle, Dendroctonus frontalis Zimm. U. S. Forest Serv. Southeast. Forest Expt. Sta. 1958. (Office Rpt., 10 pp.)

Figure 8.--Two attempts to induce beetle attack on pines. In A, a shortleaf pine was caged with sections of infested bark. Tagged trees are ones on which subsequent attack was induced. In B, an infested bolt was caged and placed in the midst of a beetle-free stand in an effort to attract beetles to the area.

ASSOCIATION OF THE BEETLE WITH TREE-KILLING FUNGI

The relationship of the southern pine beetle to fungi has been studied intensively. Most of the work has been concerned with the blue stain fungi. Craighead (1928) noted that complete girdling of the cambium and phloem by the beetle was not entirely responsible for the rapid death of the trees, and he pointed out that blue stain probably hastened their death. Craighead and St. George (see footnote 2) reported that heavily blue-stained trees were notably drier than unaffected trees. In cross sections, blue-stained portions were relatively dry, but the adjacent, unstained wood was saturated. Later studies indicated that there was a relationship between moisture content of the stems and the development of blue stains (see footnote 6). The blue stain developed best under conditions of decreased moisture and increased air supply. Beetle development and blue stain development apparently proceeded together. Dendroctonus frontalis was always accompanied by blue stain fungi, and when the brood failed to develop the fungus also failed.

Ceratocystis minor is the blue-staining fungus specifically associated with the southern pine beetle. Rumbold (1931) originally described it as Ceratostomella pini Munch. when she also described its various stages. Nelson and Beal (1929) showed that the southern pine beetle was a factor in the spread of the fungus. Of 218 zones of blue stain in shortleaf pine attacked by the beetle, 97 percent were found to be directly associated with the entrance holes of the beetle. Death of the trees was considered the result of the combination of mechanical injury caused by the beetle and the action of the blue stain fungus. They further stated: "Bluestain in southern pines, except in association with beetle attack, is uncommon, although it occasionally is found in pines which have been severely wounded, such as dry faces of turpentined trees." Additional inoculation experiments with blue stain fungi further demonstrated that it could kill pines (Nelson, 1934). If the entire cross section became stained, death invariably resulted. Because the fungus brought about a reduction in water content in uninfested trees favorable for brood development, it was believed that C. minor was probably indispensable to the southern pine beetle. Subsequent laboratory experiments, however, showed that the yeasts and blue stain fungi generally found in association with the insect were not essential for the development of adults from the egg (Holst, 1937). This was supported by the fact that beetles developed successfully from sterilized eggs. Hetrick (1949) reported that the fungus does not always accompany the southern pine beetle and that the beetle can infest trees and develop healthy broods in its absence. Although these two organisms may develop independently, it is doubtful whether either could be very successful in the absence of the other. This is a symbiotic relationship where the presence of the beetle is essential to the optimum development of the fungus and vice versa.

Bramble and Holst (1935, 1940) have reported that a number of fungi and yeasts are introduced into pines by Dendroctonus frontalis. An unnamed basidiomycete and C. minor were reported as capable of killing trees upon inoculation if the inoculation points encircled the stems of the trees. They further found: "Fungus infection of the sapwood which followed infestation of

living pines by Dendroctonus frontalis was not a simple infection by a single fungus but a complex invasion accomplished within a short period by a number of fungi." Contrary to what had been expected, the most prominent invader of the outer sapwood immediately following attack was not C. minor. In the early stages it was accompanied and even preceded by other fungi. The most prominent early invaders were Dacryomyces sp. and Pichia pini (Holst) Phaff. However, in later stages C. minor rapidly penetrated the inner growth rings and appeared to take the lead in further penetrations of the sapwood. These observations were substantiated by inoculations that showed that Dacryomyces sp. and P. pini alone could penetrate only a short distance into the sapwood of healthy trees. The infected tissue was confined to the external area affected by the removal of bark. In contrast, C. minor alone was able to penetrate to the center of inoculated stems of healthy trees. It was concluded that none of the fungi played more than an assisting role in killing trees, because even C. minor required wounds of considerable tangential extent before it could seriously damage a healthy stem. The fungi just mentioned are considered primary; others isolated were secondary and not involved in the death of trees.

Chiefly, fungi accompanying beetle attacks stop conduction and bring about the death of trees more rapidly than could be accomplished by the mechanical injury caused by the beetle alone (Bramble and Holst, 1940). Following the stoppage of conduction there is a reduction of the water content of the stem because of water withdrawal by the transpiring crown and the inability of the water to pass through the infected stem from the roots.

Caird (1935) reported that the role of Ceratocystis minor and related fungi appears to be an acceleration of the drying of the tree bole. After beetle attack, drying takes place in the outer rings (the outer rings failed to conduct dye solutions) and various fungi enter the wood. The capacity for conduction is lost first by the outer rings and proceeds progressively toward the center. As this condition advances toward the center of the tree, the water supply to the leaves is cut off and they die (fig. 9). Failure of the outer rings to conduct is intimately associated with the drying of the wood. The failure of the wood to conduct dye solutions was also associated with the penetration of the wood by fungi. C. minor and an unidentified fungus were the only fungi capable of penetrating deeply into the wood during the early stages of attack. Inoculations showed that C. minor growing alone was capable of killing trees. The unidentified fungus was not tested.

Craighead and St. George (1940) observed that pines lightly attacked in the fall by the beetle and from which no brood emerged the following spring received sufficient inoculation of the blue stain fungus to cause the death of the trees the following spring.

Optimum development of C. minor and perhaps other fungi does not occur unless the southern pine beetle is present. It is also probable that rapid increases in beetle populations are made possible by the action of these fungi in creating a more favorable environment for insect development. This symbiotic relationship may, in part, explain the sudden appearance of infestations where formerly the beetle could not be found.

Hetrick (1949) reported trees infested with southern pine beetle and with rhizomorphs of the mushroom root rot, Armillaria mellea (Vahl.). This root rot fungus apparently weakened the tree before beetle attack.

Figure 9.--Cross-section of pine killed by the southern pine beetle showing blue stain extending from beetle entrance holes to the heartwood.

Predators

Several insect predators have been observed attacking the southern pine beetle:

Insect predators of the southern pine beetle

Predator family and species	Stage attacked
Anthorcoridae	
Lyctocoris elongatus (Reuter)	Nymphs and adults feed on eggs and larvae
Scolopscelis flavicornis (Reuter)	Nymphs and adults feed on eggs and larvae
Cleridae	
Enoclerus quadriguttatus Oliv.	
Priocera castanea (Newman)	
Thanasimus dubius (F.)	Larvae feed on larvae, adults on adults
Ostomidae	
Temnochila virescens (F.)	Larvae feed on larvae and pupae, adults on adults
Tenebrionidae	
Hypophloeus cavus Lec.	
Hypophloeus parallelus Melsh.	
Tenebroides collaris (Strum.)	Larvae feed on larvae and pupae, adults on adults
Dolichopodidae	
Medetera sp.	

Fronk (1947) found that the beetles *Tenebroides collaris* (Strum.), *Temnochila virescens* (F.), and *Thanasimus dubius* (F.) were very active; the larvae feed on larvae and pupae of *Dendroctonus frontalis*, and the adult predators feed on adults. One larva of *T. dubius* was observed feeding on 96 larvae of the southern pine beetle before it pupated. Fiske (1908) observed that it was not uncommon to find beetle-infested trees in which the brood had been almost entirely destroyed by this predator.

The nymphs and adults of two anthrocorids, *Lyctocoris elongatus* (Reuter) and *Scolopscelis flavicornis* (Reuter), are active feeders on the eggs and larvae of the southern pine beetle (Fronk, 1947). *Medetera* sp. (Dolichopodidae), when present in sufficient numbers, has been reported capable of reducing beetle populations slightly (Fiske, 1908). Several other species, including the clerids *Enoclerus quadriguttatus* Oliv. (Chamberlin, 1939) and *Priocera castanea* (Newman) (Boving and Champlain, 1921), have been observed preying on the southern pine beetle. The tenebrionids

Hypophloeus cavus Lec. and H. parallelus Melsh. have been observed in brood galleries and pine bark (Hopkins, 1899).

In 1892 Hopkins (1899) released 2,200 specimens of Thanasimus formicarius L., the European bark beetle destroyer, in West Virginia. These clerids were collected in Germany for the express purpose of combating the southern pine beetle, and marked the first importation of natural enemies into the United States to combat destructive forest insects. Unfortunately, the host population collapsed before these insects could become established, and no field recoveries have ever been made.

Fronk (1947) found that: "Six different species of mites were associated with D. frontalis under the bark. Dendrolaelaps sp. (Laelaptidae) appears to be a new species and is the first record from this country. Histogaster carpio K. (Acaridae) and Parasitus sp. (Parasitidae) were observed feeding on the larvae of D. frontalis. Zerocoseius sp. (Laelaptidae) and Oribatoidae mites were present, but their relationship is unknown. Uropoda sp. was probably the most numerous of the mites. Although this mite is not parasitic on the southern pine beetle, it may hinder its dispersion by its phoresitic attacks."

About 80 percent of the beetles that emerged from eggs in an insectary had Uropoda sp. or their hairlike pedicels attached. Hetrick (1940) stated: "Mites were found on the bodies of 17 percent of the new adults of the overwintering brood and on 62 percent of those of the first brood of Dendroctonus frontalis emerging in the insectary, but no information was obtained on their importance in the field. Specimens were determined by H. E. Ewing, Entomologist of the United States National Museum as follows: two species of the family Parasitidae; one of the family Uropinae; one of the family Dameosmidae; and one of the family Cheltidae, genus Cheltia."

Woodpeckers have been observed to strip the bark from trees infested with the southern pine beetle (Hopkins, 1899; St. George, 1931; see also footnotes 1 and 8). In one infestation woodpeckers were noted working on 7.6 percent of the infested trees (see footnote 8) and have been reported as reducing broods to one-third to one-fourth of their original number (see footnote 1). St. George (1931) reported that hairy woodpeckers stripped bark from infested trees except where adult beetles had largely emerged. In stripping the bark they were responsible for killing many more beetles than they consumed because large numbers of the larvae were exposed to the cold. It has been reported 12/ that 77 percent of the southern pine beetle larvae in the dry outer bark of trees attacked by woodpeckers were killed by low temperatures, while only 44 percent of such larvae were killed in trees not attacked by woodpeckers. It seems unlikely that woodpeckers are very effective in reducing epidemics of the southern pine beetle, but they are probably quite effective in reducing the beetle in the endemic state and preventing populations from building up (fig. 10).

12/ Southeastern Forest Experiment Station. Semi-annual progress report, July-December 1957. (Unpublished, pp. D14-16.)

Figure 10.--Woodpecker feeding signs on pine infested with the southern pine beetle.

The relationship of secondary insects to the southern pine beetle is poorly understood. With the exception of such cerambycids as Monochamus titillator (F.), Acanthocinus nodosus (F.), and Xylotrechus sagittatus (Germ.), known to be competitors for food (see footnotes 1 and 3), most other insects are reported only as associates of the southern pine beetle (Craighead, 1950; see also footnotes 2 and 3). Hopkins (1899) reported great numbers of beetles killed by Monochamus spp., but Beal and St. George (see footnote 1) found Monochamus larvae nowhere numerous enough to destroy more than half the

brood. MacAndrews (see footnote 3) pointed out that the relationship between cerambycid larvae and southern pine beetle mortality is more complicated than appears on the surface. He stated: "If frontalis brood development begins before or immediately after oviposition by cerambycids the brood mortality of frontalis is not increased in thick barked trees." If they fail to get a start, considerable mortality results, regardless of bark thickness. When the bark was less than three-quarters of an inch thick, most of the pupae were destroyed; only those in the outer bark escaped.

Parasites

Hopkins (1899), Fiske (1908), Muesebeck (1938), Hetrick (1940), and Chamberlin (1939) have studied the insect parasites of the southern pine beetle.

Insect parasites of the southern pine beetle

Parasite family and species	Stage parasitized
Braconidae	
Bracon pissodis Ashm.	Larva and pupa
Coeloides pissodis (Ashm.)	
Compylonerus (Bracon) mavoritus (Cress.)	
Dendrosoter sulcatus Mues.	
Doryctes sp.	
Ecphylus (Sactopsus) schwarzii Ashm.	Larva
Spathius canadensis Ashm.	
Eulophidae	
Tetrastichus thanasimi Ashm.	On Thanasimus dubius
Pteromalidae	
Cecidostiba dendroctoni Ashm.	
Heydenia unica C. and D.	
Roptrocerus (Pachyceras) eccoptogastri Ratz.	
Torymidae	
Liondontomerus (Lochites) sp.	
Stratiomyidae	
Microchrysa polita (L.)	Larva
Tachinidae	
Tachina sp.	On Thanasimus dubius

Fiske (1908) stated: "It is only in rare instances that all the individuals of a brood of wood or bark borers are equally exposed to the attack of any one parasite, and a proportion will almost always escape." He studied the southern pine beetle and found striking differences in the proportion of parasitized individuals in different trees and at various heights in the same tree. In the tops of large trees or in small trees with thin bark, braconid parasites attacked 45 percent of the larvae; lower down on the same trees (in the case of large trees) these parasites were seldom present. Such conditions become

more important when different host trees and parasite species are involved and have a great influence upon the effectiveness of parasites.

Furthermore, although hyperparasites may not greatly reduce the effectiveness of primary parasites, various predators undoubtedly do since at times they will attack both parasites and hosts with like freedom. When a predatory species such as Thanasimus dubius becomes as numerous as it often does in trees infested with the southern pine beetle, a great many parasites will be destroyed along with the bark beetles.

Hetrick (1940) reared the following species (listed in order of importance) from Dendroctonus frontalis: Coeloides pissodis Ashm.; Cecidostiba dendroctoni Ashm.; Spathius canadensis Ashm.; Heydenia unica C. and D.; Roptrocerus eccoptogostri Ratz.; and Dendrosoter sulcatus Mues. He found that parasitism of the overwintering brood was 0.39 percent and that of the first brood was 10 percent.

Fronk (1947) reported that Microchrysa polita (L.), a stratiomyid, is parasitic in the larval stage. The most abundant parasites were Coeloides pissodis and Cecidostiba dendroctoni. These parasites were present throughout the year and undoubtedly contributed to the reduction of the southern pine beetle.

Nematodes and Pathogenic Organisms

Several nematodes attack the southern pine beetle and Hetrick (1940) reported that two were associated with the beetle. One, belonging to the genus Anguillonema, was a true endoparasite; the other, belonging to the genus Aphlenchoides, appears to be only an associate. The larvae of this nematode attach themselves beneath the elytra of adult beetles, apparently for transport. Massey (1957) recovered parasitic females of Aphelenchulus barberus n. sp. from the southern pine beetle; the males were not parasitic.

Anguillonema sp. has been reported as infesting a large portion of the adult beetles and as being responsible for heavy mortality to broods of the beetle (Hetrick, 1940). This endoparasitic nematode, together with an entomophagous fungus of the genus Beauveria, was considered largely responsible for the collapse of a bark beetle epidemic in Virginia (Hetrick, 1941).

The role of diseases in the regulation of the southern pine beetle populations is largely unknown. No bacteria or viruses have been reported as attacking the beetle; however, two fungi have been found to be associated with the insect. In a recent report (Southern Forest Experiment Station, 1955b) on an instance of natural control in Alabama, a white fungus was found associated with dead bark beetles. This may be the same fungus discovered by Hopkins (1899) and later identified as Cylindricola dendroctoni Peck. Harrar and Ellis (1940) isolated a species of Beauveria and demonstrated its pathogenicity to Dendroctonus larvae, and Harrar and Martland (1940) have demonstrated the mode of infection, action within the host, and methods of fructification of this pathogen.

PHYSICAL CONTROL AGENTS

Temperature Effects

It appears that climatic factors are more efficient than biological agents in the regulation of populations. It has been shown that low temperatures are capable of killing a large portion of the overwintering brood (Beal, 1927, 1933; see also footnotes 6 and 13). Hopkins (1899) reported that an outbreak in West Virginia subsided suddenly because of climatic conditions and the action of one or more diseases. From what is now known, it is probable that low temperature alone caused the sudden collapse of the outbreak. In North Carolina, outbreaks following a succession of mild winters have been terminated by cold winters (Beal, 1933). It has been concluded that mild winters and soil moisture deficiencies are important factors contributing to outbreaks in the southern Appalachians (Merkel, 1956).

At air temperatures of 10° F., larvae in the inner bark suffered 100-percent mortality, but no mortality occurred to those occupying the outer bark (Beal, 1933; see also footnote 6). Differences in mortality between larvae occupying the inner bark and outer bark appear to be related to moisture content. The moisture content of the inner bark (phloem) was much higher than in the outer bark and caused the high mortality of larvae occupying the inner bark (Beal, 1933; see also footnote 6). Osgood (see footnote 13) found mortality in the outer bark to vary with bark thickness. At times he found considerable survival of small larvae in the inner bark and attributed this to lower phloem moisture content.

In field observations, Beal (1933) found that some pupae died at 0° F. and adult mortality was heavy. At -5° F., 100-percent mortality occurred to larvae and adults in the outer bark, and pupal mortality was 90 percent. St. George and Beal (see footnote 6) reported complete brood mortality at temperatures between 0° F. and -5° F. No mortality occurred to the egg stage at these temperatures. In laboratory experiments, Fronk (1947) found that 100-percent mortality occurred to all stages (including the egg) maintained for longer than one week at 0° F. Some eggs hatched successfully after an exposure of no longer than one week, but all larvae died. Beal (1933) stated that in spite of the resistance of the eggs, the small number of broods which overwintered in that stage eliminated the likelihood of the survival of large numbers of eggs. Occasionally broods were unaffected by low winter temperatures, particularly those found in a narrow strip of bark on the bottom of logs lying on the ground. Thin-barked, second-growth pines offered little protection to hibernating larvae because low temperatures for short periods were almost as effective as those of longer duration.

High summer temperatures are not a natural limiting factor; however, in felled logs exposed to the sun during the summer months, subcortical temperatures as high as 112° F. occurred when the air temperature was between 70° and 80° F. and resulted in complete brood mortality (Beal, 1933). Some mortality of larvae and pupae began to occur at 100° F.

13/ Osgood, E. A. Mortality of the southern pine beetle due to low temperatures in the southern Appalachians. U. S. Forest Serv. Southeast. Forest Expt. Sta., Asheville, N. C. 1958. (Office Rpt., 13 pp.)

APPLIED CONTROL METHODS

Earliest methods of controlling the southern pine beetle included: (1) burning the infested bark; (2) converting the material into lumber and burning the slabs; or (3) placing unbarked logs in water (Hopkins, 1909b). It is necessary to burn the bark because larvae, pupae, and adults are concealed in it. Felling and limbing infested trees and exposing them to direct sunlight has also been recommended (St. George and Beal, 1929). More recently, Hetrick (1949) recommended that infested bark be dumped into ponds or sluggish streams. Since no adults emerge when the bark is placed in water, a considerable population reduction may be accomplished.

Much work has been conducted on the introduction of chemicals into the sap stream of standing trees (Craighead and St. George, 1930, 1938; see also footnotes 1 and 6). Workers were concerned primarily with killing the beetles to prevent their spread, and not with saving the trees. The most serious difficulty encountered was the stoppage of conduction and the subsequent interference with the movement of chemicals through the tree caused by the development of blue stain (fig. 11). Craighead and St. George (1938) stated: "...with the southern pine beetle in shortleaf pine in the South, these blue stains will permeate the outer layers of sapwood within 5 to 7 days after attack, and it is rarely if ever possible to obtain effective distribution of the chemical or destruction of the bark beetle unless the trees are treated within this time. This limits the usefulness of this method in the Southeast--in fact makes it really impractical for forest work."

In recent years toxic oil sprays which penetrate and kill the beetles in the bark have been used. Workers at the Southern Forest Experiment Station tested a number of formulations of benzene hexachloride (BHC), orthodichlorobenzene, trichlorobenzene, chlordane, and DDT against the beetle. 14/ Best kill was obtained with 0.5 percent gamma BHC in fuel oil and good results were obtained with 0.25 percent gamma BHC in oil (fig. 12). These formulations were recommended and applied in large-scale beetle control projects. Other formulations gave unsatisfactory control or were considered too expensive for use in forest spraying.

Speers et al. (1955) found that benzene hexachloride was more effective than orthodichlorobenzene or ethylene dibromide in controlling the beetle. Trees were treated with 0.5 percent gamma BHC in fuel oil; orthodichlorobenzene, one part to five parts fuel oil; and ethylene dibromide, three pounds in five gallons of fuel oil. Counts of emergence holes indicated that BHC gave 89 percent control and that orthodichlorobenzene and ethylene dibromide gave 77 percent control. More than 99 percent of the beetles which emerged from logs treated with BHC died within three days. Beetles emerging from logs treated with orthodichlorobenzene and ethylene dibromide lived as long as those emerging from the untreated trees. Procedures currently recommended for control of the beetle through the use of toxic oil sprays may be found in an illustrated booklet by McCambridge and Rossoll (1957).

14/ Southern Forest Experiment Station. Quarterly Rpt. (Oct.-Dec.). 1950.

Figure 11.--Equipment used to inject chemicals into the sap stream of pines to control the southern pine beetle.

Figure 12.--Spraying logs with benzene hexachloride to control the southern pine beetle.

SURVEYS

Aerial sketch mapping is the most economical method of detecting and appraising timber losses caused by the southern pine beetle; this method as used in Texas and Mississippi has been described by Heller et al. (1955). Studies were conducted in the southern Appalachians to determine how accurately southern pine beetle infestations could be mapped from the air (Aldrich et al. 1958; Southeastern Forest Experiment Station, 1957). If single trees and infestations of 2 to 5 trees are to be mapped, the observation strips should be limited to one-half mile. When small infestations are not plotted, mile-wide strips are adequate. Flights should be made at altitudes of 1,000 feet and at speeds no greater than 100 miles per hour.

Coyne et al. (1954) compared the accuracy and cost of aerial sketch mapping, black and white aerial photos, the operation recorder, and color aerial photos. Aerial sketch mapping was the least expensive, followed by black and white photos, the operation recorder, and color photos. For detecting insect damage, color film has proved more accurate than panchromatic with a red filter (Heller et al., 1959). Color photography would be most useful when the location of infested trees had to be mapped with a high degree of accuracy.

Lee (1954a) developed a unique method of locating the beetle at low population levels. Logs were examined for evidence of attack on skidways in log concentration yards of large lumber companies. These logs are so marked that they can be traced to their area of growth. By this method hundreds of suspect logs from many areas may be examined in a short time.

SUMMARY

Although considerable work has been done with the southern pine beetle, factors regulating beetle populations are poorly understood. Little is known of the basic physiology or ecology of the insect, or how changes within the host tree affect survival. The role of attractants and repellents in the selection of host trees is unknown, nor is it known whether toxic substances in the host are responsible for the failure of attacks and survival of the broods within the trees.

Studies have been conducted only under epidemic conditions; indeed, it is extremely difficult to detect the insect at endemic levels. Long-term studies have not followed the insect through endemic and epidemic periods. New aerial survey methods are being developed to locate insect populations. Environmental factors have not been carefully analyzed and compared under endemic and epidemic conditions; minor changes may prove very important to population increase or decrease. Rearing methods have met with indifferent success and failure to develop adequate rearing techniques has impeded both physiological and ecological studies in the laboratory and in the field.

Efficient chemical control methods have been worked out for the southern pine beetle, but such methods are only temporary remedies. They are stopgap measures and do not get at the basic problem.

The problem is to develop resistant trees and to regulate conditions so that the beetle populations are not able to reach outbreak proportions. Only through the development of satisfactory silvicultural controls can we eliminate costly temporary chemical control measures. In order to develop such controls basic studies must be started, and studies of the effects of stand composition as well as insect and tree physiology and ecology must be undertaken.

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Agriculture Asheville

Station Paper No. 129 September 1961

SOME APPLICATIONS OF DANGER RATINGS IN FOREST FIRE CONTROL AND MANAGEMENT

by

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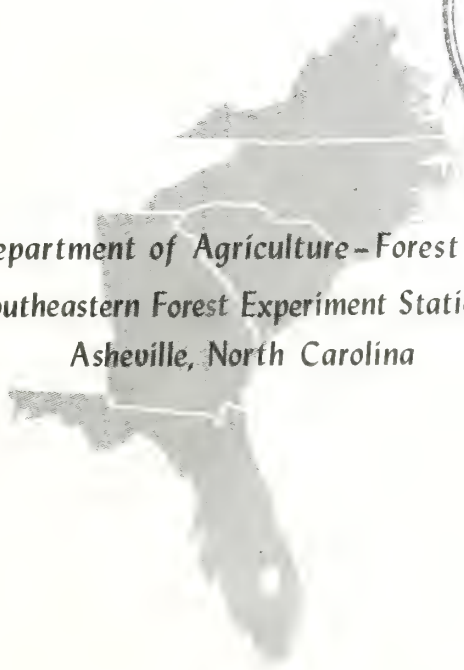

U.S. Department of Agriculture - Forest Service
Southeastern Forest Experiment Station
Asheville, North Carolina

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Many workers have contributed to the development of uses of fire danger measurements and procedures discussed in this paper. Principal acknowledgment is due J. J. Keetch who gave many helpful suggestions during the preparation of this report.

SOME APPLICATIONS OF DANGER RATINGS IN FOREST FIRE CONTROL AND MANAGEMENT

by

Ralph M. Nelson

INTRODUCTION

The system of measuring forest fire danger developed at the Southeastern Forest Experiment Station is used throughout the Eastern and Southern regions of the United States. At last count, 814 fire danger stations were operated by state, federal, and private fire control agencies in these regions. Although a number of publications have been issued on the location, operation, and maintenance of danger stations, there is only fragmentary published material on the many possible uses and applications of danger measurements.

The purpose of this paper is to summarize and explain the major uses of fire danger ratings and to present methods of analyzing fire and fire danger records. All uses are not listed, and all may not be applicable in every protection unit, but those described have been found useful in specific areas.

DERIVATION OF BURNING AND BUILDUP INDEXES

Before discussing the application of danger measurements, the system used in measuring danger in the East and South (2, 6, 8) should be briefly described. Four variables are taken into account: dryness or greenness of lesser vegetation, wind speed, upper fuel (thin surface layer) moisture as estimated from thin basswood slats, and relative dryness of lower fuels called the buildup index. When these variables are integrated on the type 8 meter used in the East, or its counterpart type 8-100 used in the South, the degree of danger is indicated on a numerical scale[1/] called the burning index. The low part of the scale indicates little danger, the upper part high to extreme danger.

1/ Type 8 meter has a burning index scale of 1 to 200, the type 8-100 of 1 to 100; in other respects the two types are similar.

The buildup index has a 100-point scale and is an indicator of the relative dryness of the several inches of fuel beneath the upper thin layer. It is obtained by cumulating drying factors based on the upper fuel moisture content as measured by thin basswood slats during rainless periods. It is reduced according to the amount of rain. For example, the index will reach its maximum of 100 points after 10 consecutive rainless days when the upper fuel moisture is less than 4 percent, or after 20 days when the moisture percent is in the 6.0 to 6.9 range. The index is reduced by one point for every hundredth inch of rain.

SIGNIFICANCE OF BURNING AND BUILDUP INDEXES

The burning index is primarily an indicator of the probability of fires starting in that it combines two major elements conducive to fuel flammability, fuel dryness and wind. Therefore, the number of fires in general increase as the index increases. This relation is illustrated by an analysis of fires and burning index for 1959 for one of the Southern States (table 1). As will be seen, there were almost 6 times as many fires per day in the 20 to 45 range as in the 2 to 5 range during the severest months and only slightly less in the other months. Similar positive correlations have been found to hold in all areas when such analyses have been made.

Table 1.--Fires per day by burning index ranges and seasons.1/ Data are for a Southern State, 1959

Burning index range 2/	January, February, March, April, December			May through November		
	Fires	Days	Fires per day	Fires	Days	Fires per day
	Number					
0 to 1	46	310	0.15	273	1150	0.24
2 to 5	754	443	1.7	652	769	0.85
6 to 17	2773	613	4.5	460	208	2.2
20 to 45	1421	144	9.9	43	9	4.8
50+	0	0	0	0	0	0

1/ Number of fires and days are totals for the 10 districts in the state.
2/ Type 8-100-0 meter. The index ranges are equivalent to danger classes on this type meter.

Rate of spread and fire intensity are also related to burning index. Keetch (4) has described the probable behavior of fires according to burning index ranges as follows:

BURNING INDEX		RELATIVE FIRE DANGER DESCRIPTIONS
METER 8	METER 8-100	
1 to 2	1	Low Fire Danger Cured grass may burn freely in the open a few hours after rain, but there is little danger of accidental fires in the forest. An occasional low-intensity woods fire may occur as the forest litter dries out. Such fires usually creep or smoulder, have irregular fingers, and consume only a portion of the surface litter. There is little danger of spotting, even with fairly high winds.
3 to 11	2 to 5	Moderate Fire Danger Fires in open cured grassland will burn briskly and spread rapidly with the wind. Woods fires start easily and spread slowly to moderately fast. The average fire in pine or hardwood litter is of moderate intensity, although heavy concentrations of draped fuel may burn hot. Short-distance spotting over the line may occur, but is usually not persistent.
12 to 35	6 to 17	Medium (or Average) Fire Danger All fine forest fuels ignite readily, and as fire intensity builds up, twigs and small brush usually become part of the available fuel. The rate of spread on level terrain is rapid, and though fires proceed primarily as a flame front, short-distance spotting is common. Unattended brush and camp fires are likely to escape. Control of fires may be of more than average difficulty, especially in the upper burning index ranges of the medium fire danger condition, unless fires are hit hard and fast. Fires burning upslope, especially if the prevailing wind is with the slope, may spread furiously and may temporarily assume characteristics of the high fire danger condition.

40 to 95	20 to 45	High Fire Danger Fires in the very dry fuels characteristic of the high fire danger condition will immediately after ignition spread rapidly, and increase quickly in intensity. There is usually considerable spotting over the line, and because of the dry fuels, spot fires are a constant danger. High-intensity fires may develop intense convection activity to a considerable height, evidenced by dark rolls and surges in the smoke column above the fire front. A favorable condition for this development is a decreasing wind aloft above a strong ground wind (described as an adverse wind profile). The worst features of high-intensity burning, such as long-distance spotting, fire whirlwinds, and strong updrafts and downdrafts, are associated with the well-developed smoke column. Fires burning in light fuels may quickly develop high-intensity characteristics when they burn into heavier fuels, or the triggering mechanism may be the result of an upslope run or two fires burning together without a change in fuel type.
100 to 200	50 to 100	Extreme Fire Danger Fires in all fuel types may burn intensely and spread furiously. Crowning and spot fires are common. Development into high-intensity burning will usually be faster and occur in the case of smaller fires than in the high fire danger condition. Fires may quickly develop a high-intensity head, or heads, each with its own active smoke column, when adverse wind profiles are present. Fires that develop headway in heavy slash or dense conifer stands may be unmanageable until the weather subsides or the fuel supply lessens.

The buildup index, as previously explained, indicates the relative dryness of several inches of fuel beneath the thin upper layer. As more fuel becomes available through progressively deeper drying, the rate of energy release from fires also becomes greater. Under similar conditions of upper fuel moisture and weather, fires will burn more intensely and will be more difficult to control when the buildup index is high than when it is low. When the index approaches its maximum, fuel layers, and to some extent the mineral soil beneath, become extremely dry. At such times firelines are hard to hold and mop up becomes increasingly difficult. On many occasions fires thought to be under control have crept under firelines in buried material and kindled fuels on the other side. Deep duff fuels or organic soils respond differently to wetting and drying than ordinary fuels on mineral soils. The buildup index therefore is not a good indicator of the relative dryness of these deep fuels.

Although in general, number of fires and acres burned increase as the burning index increases, wide differences are sometimes found among days and protection units having the same burning index. For example, 5 fires may occur in a protection unit on a day with a burning index of 50 and none at all on another 50-index day. These differences occur because of the unpredictable activity of fire starters. Nevertheless, a day with a certain burning index has a certain fire potential whether many or no fires occur.

The burning and buildup indexes described provide the fire control manager with meaningful numbers that indicate probable fire occurrence, rate of spread, intensity, and resistance to control. When intelligently interpreted in terms of fuel types and terrain, the indexes supply a highly useful basis for day-to-day fire control planning and action.

USE OF DANGER RATINGS IN PREPAREDNESS PLANNING

Fire danger in the East and South, unlike some western regions where danger normally builds to a seasonal peak which persists for long periods, can fluctuate greatly from day to day. For this reason it is only during exceptional years that a fire control organization must be maintained at full strength for extended periods. To do so in an average year would be unjustifiably wasteful. To be most effective, however, fire control forces must be organized to adjust promptly to easy days and difficult days that often follow each other in quick succession.

Few if any fire control organizations are large enough and flexible enough to cope with the "worst probable" fire load. The prudent fire control supervisor should, however, have sufficient knowledge of his terrain, fuel types, danger ratings, and probable risk, as well as suppression facilities available, to meet "average bad" conditions with prompt and effective action. In addition he should know when extreme danger impends so that extraordinary precautions can be taken.

Attempting to meet fire situations as they arise without advance planning is likely to be costly and ineffective, as has been abundantly demonstrated in the past. An action plan based on the calculation of probabilities, that is the probable number of fires that will start and how they will behave, is essential to the soundest disposition of control forces. Such plans have been developed from judgment alone, but analysis of past measured danger as related to fire occurrence and behavior can take out much of the guesswork in their preparation.

As a first step in preparedness planning, an analysis of number of days, fires, and acres burned by burning index ranges for a period of several years is suggested for each protection unit. Table 2 is a sample analysis. It is clear from the tabulation that a decided increase in the fire load can be expected with an increase in the burning index range, although its load size varies by seasons.

Table 2.--Days, fires, and acres burned by burning index ranges and seasons. Data are for a Mid-Atlantic State protection unit, 1955-1959

Burning 1/ index range	Days	Fires	Acres burned	Fires per day	Acres per day	Acres per fire
			Number			
JANUARY-MAY, NOVEMBER-DECEMBER						
0 to 10	502	57	124.4	0.1	0.2	2.2
11 to 20	238	148	885.3	0.6	3.7	6.0
25 to 40	173	258	1,077.6	1.5	6.2	4.2
45 to 80	125	450	2,930.7	3.6	23.4	6.5
85+	23	180	1,676.3	7.8	72.9	9.3
Total	1,061	1,093	6,694.3			
JUNE-OCTOBER						
0 to 10	612	59	102.4	0.1	0.2	1.7
11 to 20	119	60	185.7	0.5	1.6	3.1
25 to 40	32	52	89.4	1.6	2.8	1.7
45 to 80	2	3	3.3	1.5	1.6	1.1
85+	0	0	0	0	0	0
Total	765	174	380.8			

1/ Type 8 meter. It has a 200-point burning index scale.

Basic data for analyses are already available to 13 Northeastern States from yearly analysis reports of fires and fire danger. These are prepared at the Southeastern Station in cooperation with Region 7 of the Forest Service and the Northeastern States. In the reports, number of days, fires, and acres burned are tabulated for months and protection units by burning index as in figure 1. Inspection of monthly values will suggest the grouping of months that will give the best seasonal averages. Burning indexes can, of course, be combined into ranges as desired.

After the probabilities of fire occurrence and size of fires by burning index ranges have been calculated, it is possible to develop a fire organization placement plan with considerable confidence. In preparing it, additional factors must be considered, such as areas of past fire concentration, accessibility, probability of normal or high risk, visibility, and values at stake. Its workability depends to a large extent on how well the planner knows his area, his astuteness in analyzing its past fire history, and in anticipating trends. It goes without saying that effective fire control planning requires thorough and continuing study of reliable fire records and of fire behavior in the field.

Burning Index	July			August			September		
	Days	Fires	Acres	Days	Fires	Acres	Days	Fires	Acres
0									
1							1		
2							2		
3							2		
4				1			2		
5				1	3	3.7			
6				1			1	1	0.2
7									
8				1	2	1.7	1		
9									
10									
11							1		
12				1	2	1.7	1		
13									
14				2	3	3.9			
15							1	1	3.0
16	1	1	2.0				1		
17									
20				4	19	21.6	2	1	.2
25	2	3	3.4	1	3	5.4	2	2	.7
30	2	13	41.0	5	23	33.8	1	3	33.2
35	4	7	15.1	1	8	7.9	1	3	9.5
40	4	20	36.0	3	20	18.3	1	8	28.1
45	3	6	4.9	1	4	628.0			
50	5	28	114.0	1	7	59.4	2	19	153.5
55	1	1	.2	2	10	9.5			
60	1	1	.2				1	8	509.2
65									
70	2	13	17.1	1	9	6.9			
75									
80	1	8	21.8	1	7	12.6			
85									
90									
95									
100+	4	41	560.4	1	4	6.7			
Unknown	1			3	1	.5	7		
TOTAL	31	142	816.1	31	125	821.6	30	46	737.6
Total B.I.	1,596			928			442		

Figure 1.--Sample report showing number of days, fires, and acres burned by months and burning index. Data are for a Northeast State protection unit, 1957.

Although placement plans can be developed on the basis of burning index alone, ranger districts on Eastern national forests have successfully used plans based on preparedness classes. 2/ In these (fig. 2), burning and buildup indexes were combined to integrate probability of fire occurrence, rate of spread, and resistance to control into five readily identifiable categories of increasing job load. Figure 3 is a sample placement plan for a hypothetical protection unit.

2/ Developed by J. J. Keetch.

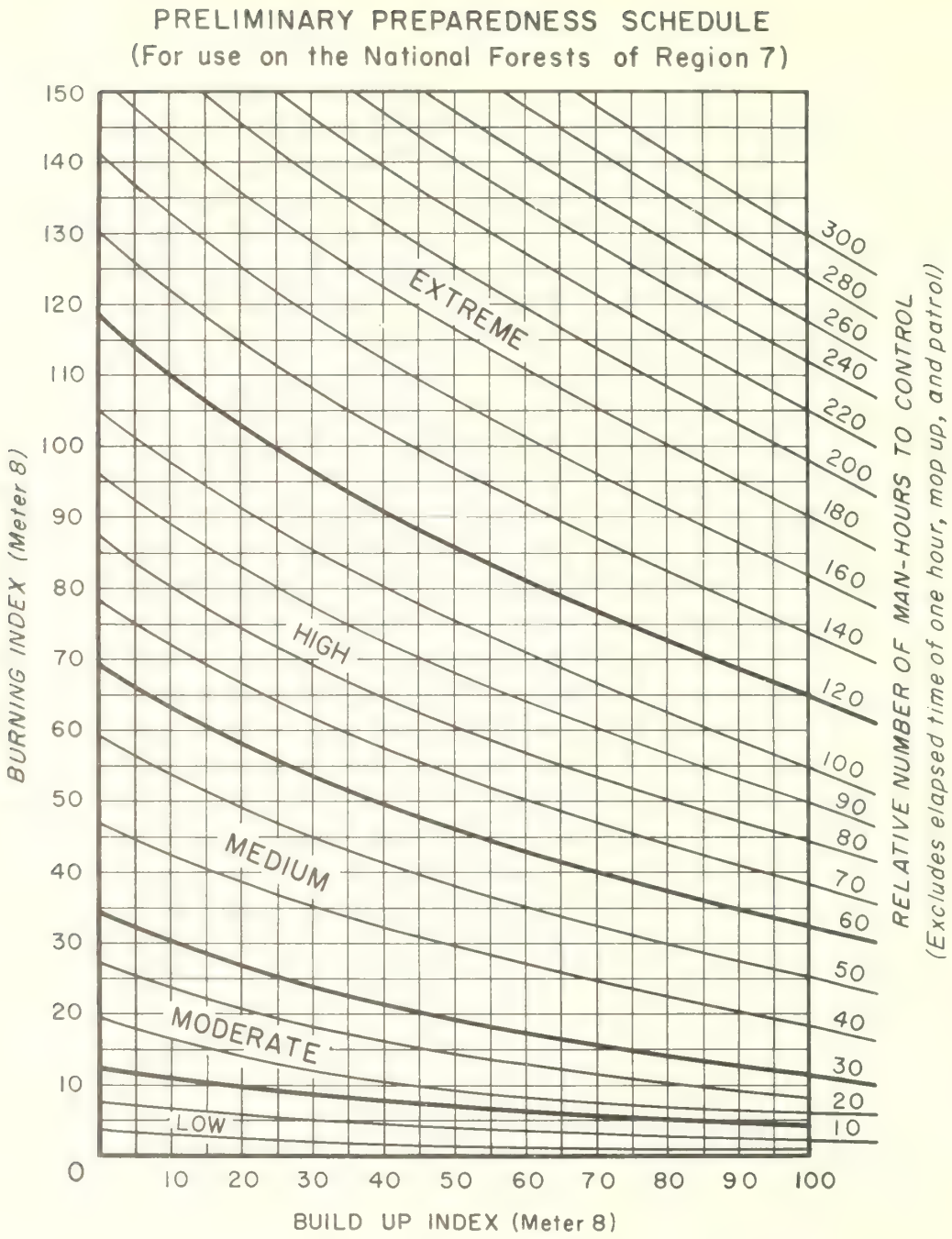

Figure 2.--Preparedness classes.

A plan such as illustrated has numerous advantages. The unit manager is better able to maintain tight control over his men and to better organize their work both for off-fire and on-fire duty. There is less chance that he will be caught unprepared by an unusual fire situation. A well-conceived plan should reduce the probability of either overmanning or undermanning and should, in the long run, make for a more effective and economical fire control program.

Position	Preparedness Classes									
	Low		Moderate		Medium		High		Extreme	
	Normal risk	High risk	Normal risk	High risk	Normal risk	High risk	Normal risk	High risk	Normal risk	High risk
District Forester	0	0	0	0	1	1	1	2	2	2
Fire Control Ass't.	0	0	1	1	2	2	2	2	2	2
Dispatcher	1	1	1	2	2	2	2	2	2	2
Service Forester	0	0	0	0	1	1	1	2	2	2
County Rangers	1	1	1	2	2	2	2	2	2	2
Lookouts										
A	0	0	2	2	2	2	2	2	2	2
B	0	0	0	2	2	2	2	2	2	2
C	0	0	0	0	0	0	2	2	2	2
Work Crews										
A	0	0	0	1	1	2	2	2	2	2
B	0	0	0	1	1	1	2	2	2	2
Standby Crews										
A	0	0	0	0	0	0	0	2	2	2
B	0	0	0	0	0	0	0	2	2	2
Ground Patrols										
A	0	0	0	0	0	2	1	2	2	2
B	0	0	0	0	0	0	0	2	2	2
Air Patrol	0	0	1	1	1	2	2	2	2	2

Figure 3.--Sample fire organization placement plan for a hypothetical protection unit in a Northeast State during the fire season. Duty status: 0, non-fire duty or off duty; 1, on call and within reach for fire duty; 2, on duty or immediately available for fire duty. High risk may result from concentration of use or other causes; poor visibility may be equivalent to high risk.

PREPAREDNESS CLASSES AS GUIDES TO DISPATCHING

Once a fire is reported, the dispatcher or other fire control officer has the difficult task of deciding on the strength of the initial task force that should be sent. In addition to danger rating, he needs to consider, among other things, the fuel type in which the fire is burning or likely to burn. Both factors have a decided effect on rate of spread and resistance to control and therefore on manpower and equipment requirements.

Major fuel types in Eastern national forests have been classified according to rate of spread and resistance to control and have been assigned a fuel type factor (table 3).

Table 3.--Fuel type classification by rate of spread and resistance to control, Region 7

Fuel type factor	Fuel type	Rate of spread	Resistance to control
1.0	Grass, ferns, weeds	High to extreme	Low
1.0	Hardwood, pine or pine-hardwood litter	Medium	Medium
2.0	Hardwood slash or blowdown	Medium	High
2.5	Pine or pine-hardwood slash or blowdown	High	High
3.0	Scrub oak	Extreme	Medium to high
3.0	Northern conifer reproduction	Extreme	High
3.5 to 4.0	Laurel and rhododendron	High to extreme	High to extreme
4.5 to 5.0	Northern conifer slash	High to extreme	Extreme

Referring to figure 2, the numbers on the right-hand margin indicate the estimated number of man-hours required to control a fire having a rate of perimeter increase equal to the fastest spreading 25 percent of the fires. The figures are also based on an assumed one-hour elapsed time (time of origin to first attack), control time of one hour, and a fuel type factor of 1.

Because the rate of perimeter increase is an average of the fastest spreading 25 percent of the fires in all fuel types, the man-hour values need to be adjusted according to the fuel type factor. Other considerations entering the dispatcher's calculations are estimated travel time and the desired time to control the fire (5 to 8 hours).

The following sample calculation illustrates the procedures that have been used by Eastern national forests to estimate the number of line workers needed:

(1)	Burning index (meter 8)	30
(2)	Buildup index	45
(3)	Man-hours (fig. 2)	40
(4)	Estimated travel time	1.5 hours
(5)	Fuel type factor	1.0 (hardwood litter)
(6)	Adjusted man-hours ($40 \times 1.5 \times 1.0$)	60
(7)	Desired control time	5 hours
(8)	Number of line workers ($60 \div 5 = 12$)	12

These calculations are simple enough but they can by no means be more than a general guide to the dispatcher. He must take into account such variables as skill and endurance of available line workers, probable increase or decrease in severity of burning conditions, slope which has the same effect on rate of spread as an increase in wind speed of several miles per hour, and values at stake. Furthermore, the procedure outlined allows for some margin of safety because it is based on the fastest spreading 25 percent of the fires. For the average fire in relatively flat terrain, some overmanning might result; for steep slopes, some undermanning.

The discussion so far has not considered the fires that spot or crown. These can be described as three-dimensional and have behavior characteristics entirely different from the usual surface fire. No way of estimating their behavior has yet been discovered but even so the burning and buildup indexes do provide some degree of warning.

DANGER RATINGS IN FIRE PREVENTION PLANNING

Many fire control organizations use danger ratings as a means of informing the public about the severity of current burning conditions. Most common communication media are newspaper articles, radio and television broadcasts, and a variety of signs indicating the day's danger with an appropriate message as to its meaning. In the Northeast, broadcasts have been used extensively. Some states provide cooperating stations with messages keyed to the day's expected danger:

> Today's fire danger will be high to extreme. The forests are very dry and burning conditions are critical. Brush pile or trash burning should not be attempted under any circumstances, and smokers should be extremely careful. The slightest spark will readily ignite a fire in all types of cover. Fires will burn rapidly with intense heat, and some crowning may occur in pine stands that will kill reproduction and cause great damage to standing timber. Burning today is an invitation to trouble.

The assumption is that prevention messages for specific times and places are more effective than generalized programs. Although the value of a particular prevention activity is hard to appraise, it seems reasonable to suppose that forthright appeals to the public during critical periods have some dissuading effect on potential fire starters.

Unfortunately, the rural segment of the public that start most of the fires in the South are not so easily reached by these media as people in more highly urbanized areas. Person-to-person contacts and strict law enforcement will likely continue to be the most potent deterrents to fire starters in the South, at least until much better lines of communication are established.

A number of states have laws empowering Governors to close forests to unauthorized use when danger from fires becomes acute. Regional foresters have similar authority to close national forests. The difficulty lies in knowing how near conditions are to the breaking point so that closure is justified. Decisions are not easily reached. Those in authority realize that closure disrupts people's plans and can cause considerable financial hardship to individuals who supply goods and services to campers, hunters, fishermen, and other woods users and workers. Another difficulty is that closure cannot be quickly invoked. The public must be given reasonable notice and there must be better than a fair chance that difficult conditions will prevail for at least some days.

The buildup index has been found to be a useful guide to woods closure during critical conditions. This is because it is an indicator of the relative dryness of the whole fuel layer (except in organic soils) and unlike the burning index is not affected by changes in wind speed and only to a slight extent by light rains. Consequently, a rising buildup index indicates an increasing potential danger. No specific point on the 100-point scale can be considered critical. However, from past experience in the Northeast, consideration should be given to closure as the index approaches 50. In one state during the difficult 1950-1952 period, 6 closures averaged an index of 52.

In contemplating closure, cooperation should, of course, be requested from the U. S. Weather Bureau fire-weather forecasters. Their 5-day predictions, especially as to the probability of rain or high winds, may well be the deciding factor.

EVALUATING FIRE PREVENTION EFFORTS

Many millions of dollars are spent in forest fire prevention each year. Efforts range from elaborate national publicity programs to person-to-person contacts. Although fire control agencies annually report number of fires and acres burned, and compare one year with another, such comparisons are relatively meaningless unless the effect of weather is taken out. One year may have much more or less severe fire weather than another and a decrease in number of fires over the past year may in reality be because of easy weather rather than the quality of the prevention job.

Through a cooperative project among 13 Northeastern States, Forest Service Region 7, and the Southeastern Station, an analysis of the relation of number of fires and acres burned to burning index has been made for the last 17 years, 1943-1959. One part of the analysis has been to determine the trend in number of fires per thousand units of burning index (occurrence rate). Figure 4 indicates such a trend for one of the Northeastern States. The pronounced downward trend clearly indicates that prevention efforts, of whatever kind, have brought about notable results. A weakness in the analysis is that we cannot yet measure the trend in risk, that is, the increase or decrease in activity of fire starters. However, it can safely be assumed that there has been an increase in the number of woods visitors and users, and therefore potential fire starters, during the 17-year period. On this assumption the decrease in fire occurrence rate is even more striking.

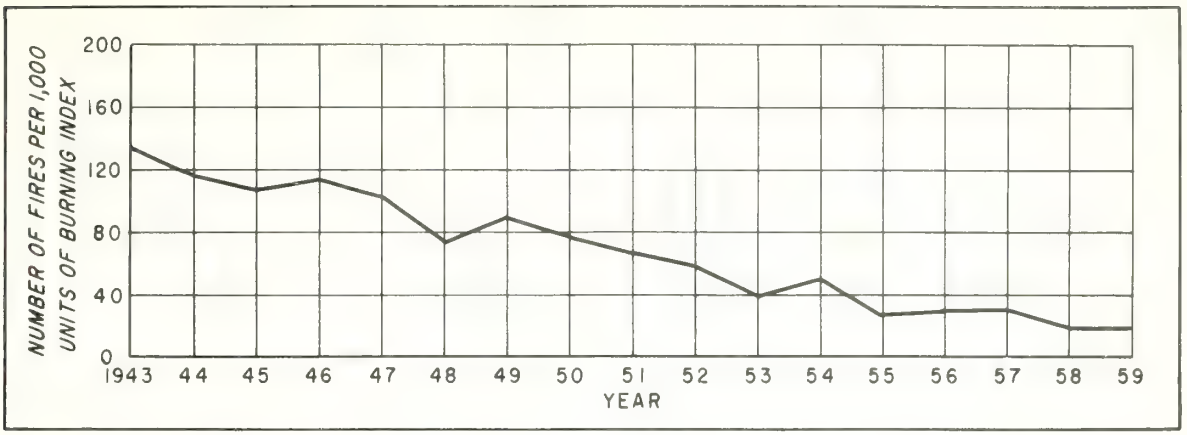

Figure 4.--Fire occurrence rate in a Northeast State by years.

The procedure used for calculating occurrence rate is simple. All that is needed is an accurate record of number of fires by dates and an adequate sampling of fire danger in a protection unit by means of properly located and operated danger stations. The total number of units of burning index, in thousands, are summed and averaged for the year and divided into the number of fires. Adjustment must of course be made if there has been a change in the number of acres protected.

Figure 5, showing how a graph of fire occurrence only can be misleading, is taken from an article by Keetch (3). The upper graph has no discernible trend and one could assume from it that no progress in fire prevention had been made during the 12-year period. Yet, in the lower graph, where the effect of weather has been taken out, it is seen that the opposite is true.

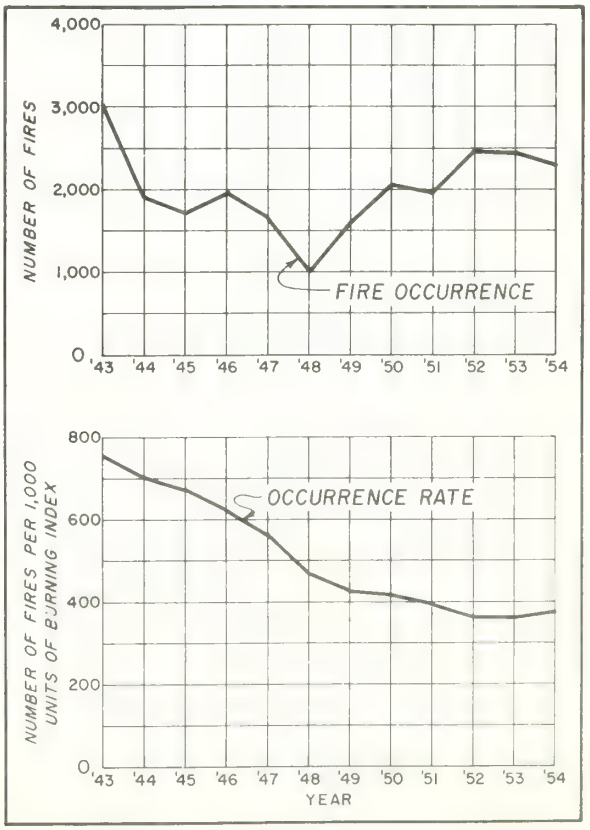

Figure 5.--Fire occurrence and occurrence rate in 13 Northeast States by years (3).

Plotted trends of occurrence rate by years can be very revealing to a fire control manager. A state or regional graph will indicate whether prevention ground is being gained or lost for the large unit as a whole, but will not pinpoint, as will graphs for individual subunits, the areas where prevention activities need to be strengthened or modified. However, subunits should not be so small that trends are likely to be obscured because of relatively few fires.

EVALUATING FIRE SUPPRESSION EFFORTS

A calculation of trends in the relation between danger ratings and acres burned can be used to judge the effectiveness of suppression efforts over a period of years. Such trends for a Northeastern State protection unit are illustrated in figure 6. A 3-year moving average was used to obtain a better measure of trend.

As in evaluating prevention efforts, the effect of weather was taken out in determining the trends in figure 6. With Class E fires eliminated from the computations, it is clear that there has been a very sizeable reduction in number of acres burned per thousand units of burning index. This fact, by itself, does not necessarily indicate the degree of efficiency of the organization, but that an increasingly higher level of fire protection is being obtained.

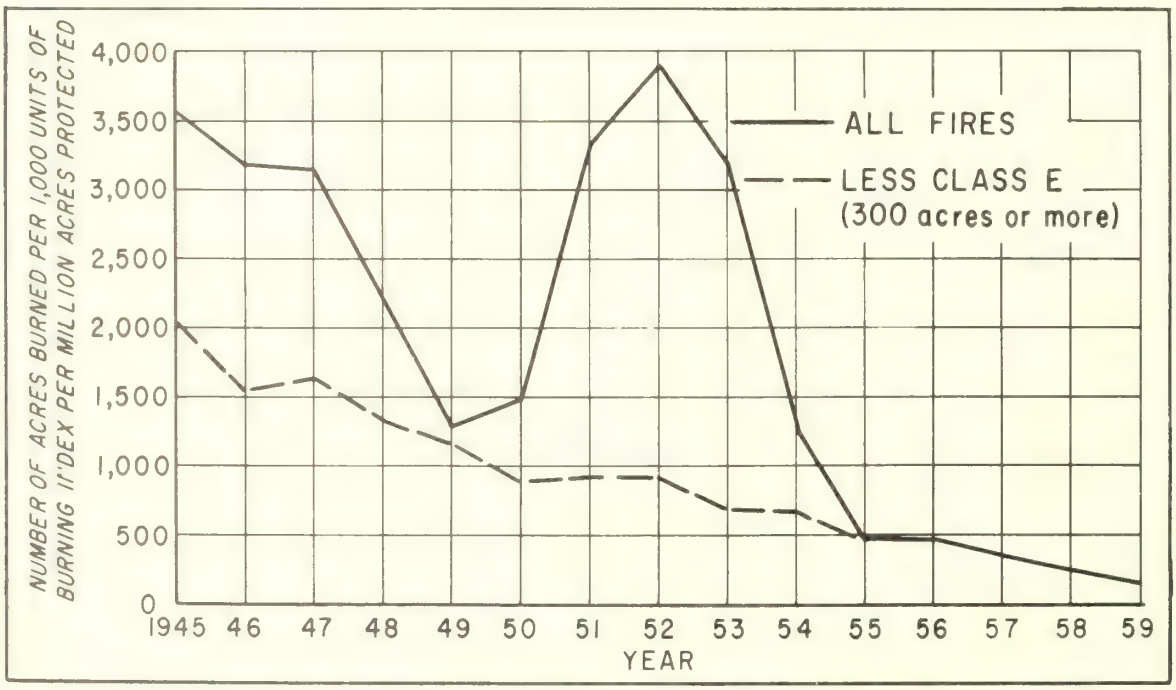

Figure 6.--Burned area rate in a Northeast State by years. Three-year moving average.

The following procedure was used in calculating the values in figure 6. Total number of fires per year was divided by the total number of burning index units in thousands per year, and this figure in turn was divided by the area protected in the unit in millions of acres as in the following tabulation. This unit had 0.434 million acres.

Year	Total acres burned	Burning index (Thousand units)	Burned area rate	Burned area rate per million acres protected
1957	1,145	7.900	145	334
1958	181	3.857	47	108
1959	213	4.429	48	111

The sum of the figures in the last column is 553; the average, 184, is the value plotted for 1959 in figure 6.

In evaluating fire suppression efforts, as well as prevention efforts discussed earlier, a fire control supervisor has the means of reaching an unbiased opinion as to the relative effectiveness of one unit compared with another. Consequently, he should be able to exercise a higher level of managerial control from a recognition of strong as well as weak units in his organization.

RATING YEARS BY SEVERITY OF FIRE WEATHER

One year can be rated against another, or against a "normal" year, according to the severity of fire weather if good records for a number of years are available. The larger the number of years, the better the rating; five should probably be the minimum.

Burning indexes for a single month for a number of years are ranked in order of magnitude and the middle value (median) is taken as the "normal" burning index. For example, if values for 9 years are ranked, the fifth item would be the median; if 10 years are ranked the median would be an average of the 5th and 6th items. In these calculations, medians are preferred to averages because they are not distorted by an exceptionally high or low value.

Monthly medians are summed to obtain the normal burning index for the period. Dividing the total burning index for any one year by the normal index gives a percent figure that establishes that year's rating on the basis of the severity of fire weather. Medians for individual months can, of course, be grouped as desired to provide season ratings.

Figure 7 is a plot of yearly ratings for a Northeastern State. From it the relative severity of fire weather for each year can be seen at a glance.

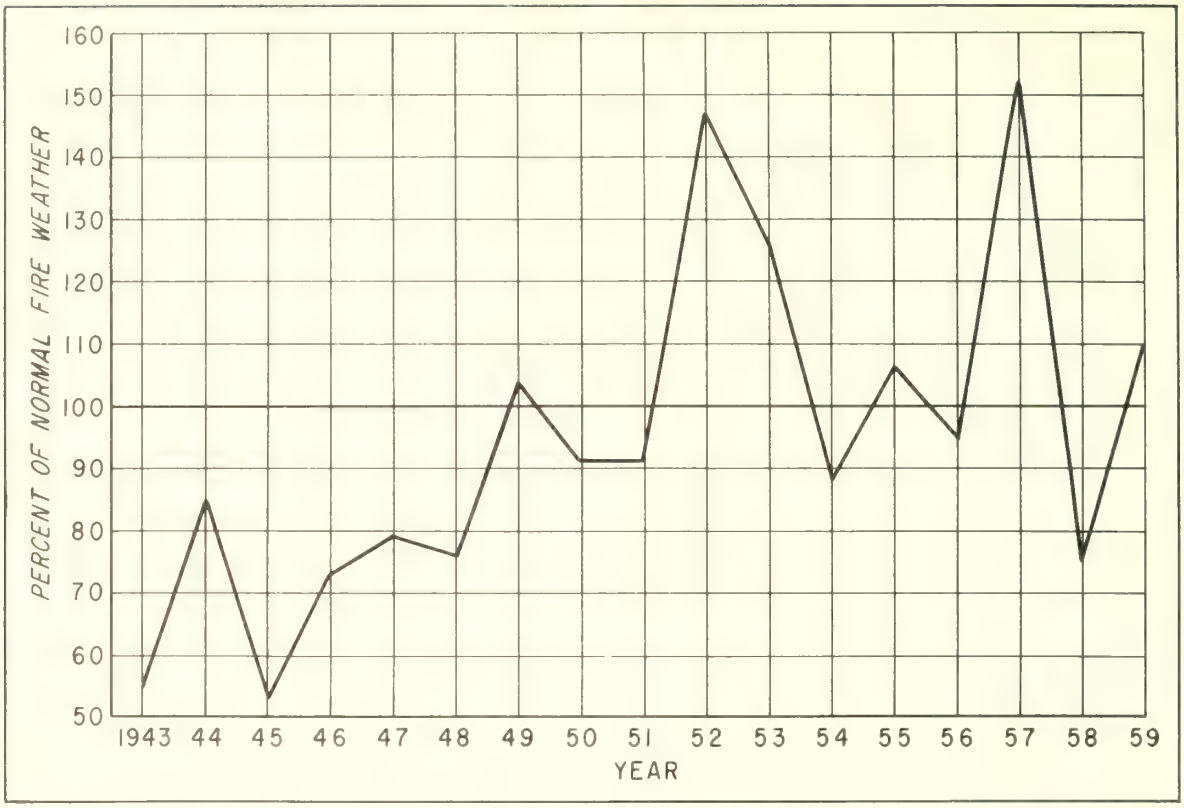

Figure 7.--Fire weather ratings for a Northeast State by years.

EXTREME FIRE BEHAVIOR

For the Nation as a whole, five percent of all forest fires burn an estimated three-fourths of the acres lost and cause even a greater percent of the damage. Most of this small percent of fires exhibit extreme behavior and are often characterized by strong convection columns, whirlwinds, violent updrafts and downdrafts, long-distance spotting and, therefore, very high rates of spread. Most fatalities among firefighters occur because of the unbelievable rate of energy release and unpredictable behavior of such fires. Moreover, the cost of control of a single fire sometimes runs into millions of dollars. Most certainly, the elimination of disaster fires is the one most pressing problem facing the Nation's forest fire control agencies.

Byram's (1) analysis work, as well as his case history study of blowup fires, indicates that certain fuel and atmospheric conditions are conducive to extreme fire behavior. Briefly, a fire has blowup potentialities when it is burning in an area of abundant dry fuel and where the speed of the winds near the surface (usually less than 1,500 feet above the fire) exceeds the speed of winds aloft. Apparently for any given wind speed, a critical rate of energy release must be reached before large-scale convection can begin. The geographic extent and periodicity of wind profiles conducive to convection are not known nor can they yet be predicted. There is evidence that adverse pro-

files most often come with winds from the Southwest and Northwest quadrants. The worst conditions appear to accompany the passage of dry cold fronts at which time the wind is usually from the Northwest or North.

None of the blowup fires in the Northeastern States studied so far have burned when both burning and buildup indexes (on the 200-point type-8 meter) were below 50. From an examination of many years of records, these indexes were reached on only 5 percent of the days. Therefore, the best insurance against disaster fires would seem to be extremely fast attack on this small percent of days of high indexes so as to contain fires, especially those in heavy fuels, before they can reach the "triggering-off" stage.

The practice of prescribed burning for fuel reduction and other purposes undoubtedly lessens the probability of conflagration-type fires in the South.

As technical advances are made in fire-weather forecasting, prediction of these extremely dangerous periods should become possible. When that time comes, with the exercise of utmost vigilance and fast attack, the probability of disaster fires should lessen in the East and South.

COMPUTING METHODS FOR FOREST FIRE AND FIRE DANGER RECORDS

Earlier sections of this paper have explained the relation of danger ratings to fire occurrence and acres burned and the several applications of these relations. The step-by-step procedures that have been developed for handling raw data are not complicated. Over the years a number of forms and methods have been devised that greatly facilitate analysis work. They are currently used in the annual preparation of forest fire and fire danger reports for 13 Northeastern States.

(1) Fire danger daily records, such as figure 8, are received from reporting danger stations at the end of each month. Condition of lesser vegetation (col. 2) is first checked because it is one of the items that causes much trouble. Observers have little difficulty in deciding when vegetation is fully green or fully cured, but during transition periods they often fail to follow instructions that have been issued (2, 8). Other items checked are the buildup factors, subtraction from the buildup index because of rain, and the burning index by setting up individual daily factors on the danger meter.

(2) The next step is to calculate the average burning index for each protection unit. This is done on the sample summary form (fig. 9). For the purpose of illustration, assume a small state with two protection units and three danger stations in each unit. The highest burning index for each day and station are entered on the summary form from the fire danger daily record and averages obtained as shown in the right-hand columns in figure 9. Averages must be rounded off to the near-

FIRE DANGER DAILY RECORD April (month) 1954

Sample (State or Forest) Sample (District) Sample (Open) (Station) John Doe (Observer)

Day of the Month	Condition of the Lesser Vegetation	9 A.M. EST			24 HOUR RAINFALL 2 P.M. TO 2 P.M. (Hundredths)			2 P.M. EST					5 P.M. EST			Highest Burning Index for the Day
		Fuel Moisture Percent	Wind Speed Miles per Hour	Burning Index	Amount of Rain Danger Station	Amount of Rain Coop. Station	Average Amount of Rainfall	Build-up Index	Build-up Factor	Fuel Moisture Percent	Wind Speed Miles per Hour	Burning Index	Fuel Moisture Percent	Wind Speed Miles per Hour	Burning Index	
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1	1	50+	8.0	1	13	25	19	15	5	6.0	6.5	35	5.3	7.0	40	40
2	1	11.0	5.0	10			0	23	8	4.0	8.0	75	3.6	6.0	65	75
3	1	8.5	3.5	15			0	29	6	5.0	5.0	50	5.0	6.5	60	60
4	1	50+	8.0	1	85	45	65	2	2	11.8	8.5	7	10.2	8.5	10	10
5	1	11.7	8.5	8			0	5	3	8.0	9.0	20	8.2	8.5	20	20
6	1	10.0	5.0	7			0	13	8	4.0	6.0	45	4.0	4.0	30	45
7	1	12.2	8.5	12	T	T	0	18	5	6.0	4.5	30	5.6	5.0	35	35
8	1	13.0	5.5	8			0	26	8	4.8	5.5	50	4.3	5.0	50	50
9	1	14.2	3.0	4			0	34	8	4.1	5.0	60	4.5	5.0	60	60
10																
11																
12																

Figure 8.--Sample fire danger daily record. Meter type 8.

est burning index figure shown on the meter. Missing records are entered as dashes; snow on the ground as 0. For example, on the 6th day, the average is of two items for Unit X, but of three for Unit Y.

(3) Shortly after the end of each year, cooperating states forward code sheets similar to figure 10 to the Southeastern Station. Each line on the form is for a single fire. For example, the first entry on the sample form means the protection unit "X" had a 0.3 acre fire on January 24 that was caused by a debris burner. The average burning index for the unit on that day was 11. This last item is entered on the code sheet after completion of step 2.

(4) Data from each line on the code sheets are punched on individual IBM-type cards, which are machine sorted and tabulated. The tabulation sheets indicate the number of fires and acres burned by protection units, months, and burning index. This information is entered on work sheets such as figure 1. The number of days by burning index for each month is taken from unit averages on the summary forms previ-

FOREST FIRE DANGER SUMMARY

Forest or State Sample Month Sample , 19

DAY	A	Unit X B	C	Total		D	Unit Y E	F	Total				Unit X ave.		Unit Y ave.			
1	25	30	55	110		17	20	60	97				35		30			
2	30	30	25	85		13	17	40	70				30		25			
3	35	30	50	115		20	60	17	97				40		30			
4	35	25	40	100		25	30	50	105				35		35			
5	38	16	30	76		30	20	30	80				25		25			
6	5	5	-	10		5	5	0	10				5		3			

Figure 9.--Sample fire danger summary form.

FOREST FIRE CODING SHEET

State Sample ( ) Unit X ( ) Sheet ___ of ___ Year ( )

County			Burning Index			Month		Day		Cause	Area													
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
0	1	3	0	1	1	0	1	2	4	6	0	0	0	0	0	3								
0	1	3	0	1	3	0	1	3	0	5	0	0	0	3	5	0								
0	2	3	0	2	0	0	2	2	7	5	0	0	0	0	1	0								
0	2	3	0	1	5	0	2	2	7	6	0	0	0	0	3	0								
0	2	7	0	3	5	0	2	2	8	6	0	0	0	0	2	0								

Figure 10.--Sample forest fire coding sheet.

ously mentioned. These monthly work sheets contain the basic data and from them number of fires and acres burned can be grouped by seasons and classes of burning index as desired. Data for units can be combined into state totals and these into regional totals.

Protection agencies having ready access to IBM-type equipment may find the tabulating procedure followed by the Southern Forest Fire Laboratory to be superior to the one described because some of the hand sorting is eliminated. In addition to punching a card for each fire, a card containing fire danger data is punched for each day. The daily cards permit machine sorting for number of days by burning index and preparation of a variety of other tabulations.

(5) A second machine tabulation of number of fires by burning index, cause, and protection unit, permits an examination of causes of fires. Records, such as in figure 11, should aid a unit manager in better directing prevention efforts. Obviously, the value of such information depends on how well the causes of individual fires are known and reported.

Range in burning index	Light-ning	Rail-road	Lumber-ing	Camp-fire	Smok-ing	Debris burning	Incen-diary	Misc.	Un-known	All causes
					Number					
					Eastern District					
0-10	1				3	2		1		7
11-20					3	4	1	4		12
25-40				1	1	6	1	3		12
45-80				3	6	15	8	9		41
85-160					4	8	5	8		25
Unknown										
Total	1			4	17	35	15	25		97
					Western District					
0-10					5	9		5		19
11-20					7	6	1	5		19
25-40		2		1	14	37	7	23		84
45-80		4		7	28	53	11	40		143
85-160	1	2			16	31	8	13		71
Unknown		1			3	9	1	5		19
Total	1	9		8	73	145	28	91		355
					State Totals					
0-10	1				8	11		6		26
11-20					10	10	2	9		31
25-40		2		2	15	43	8	26		96
45-80		4		10	34	68	19	49		184
85-160	1	2			20	39	13	21		96
Unknown		1			3	9	1	5		19
Total	2	9		12	90	180	43	116		452

Figure 11.--Sample tally sheet showing number of fires by cause and burning index ranges. Data are for a Northeast State.

USE OF DANGER RATINGS IN FIRE DAMAGE APPRAISAL

No accurate yet practicable method for appraising damage caused by individual fires has so far been devised. This is partly because of the infinite variety of fuel and stand conditions and fire intensity that are found and partly because of inability to assess damages to so-called intangibles, such as recreation, wildlife, watershed, soil, and esthetic values.

In spite of limitations imposed by lack of knowledge of fire effects, a set of damage appraisal tables (7) were prepared that have been widely used in the East and South. The tables are based on average stand values and average stand losses. If adjusted to current stumpage prices, they provide a fairly acceptable means of estimating dollar losses caused by large groups of fires.

Burning index is one of the major variables in the tables because, in general, the higher the burning index the greater the fire intensity and hence, greater physical damage to the stand (fig. 12). As an example, an April fire in a satisfactorily stocked pine-hardwood stand, predominantly in the 2- to 4-inch diameter class, is estimated to cause 6 times the dollar loss on a day with a burning index of 70 than on a day with an index of 2.

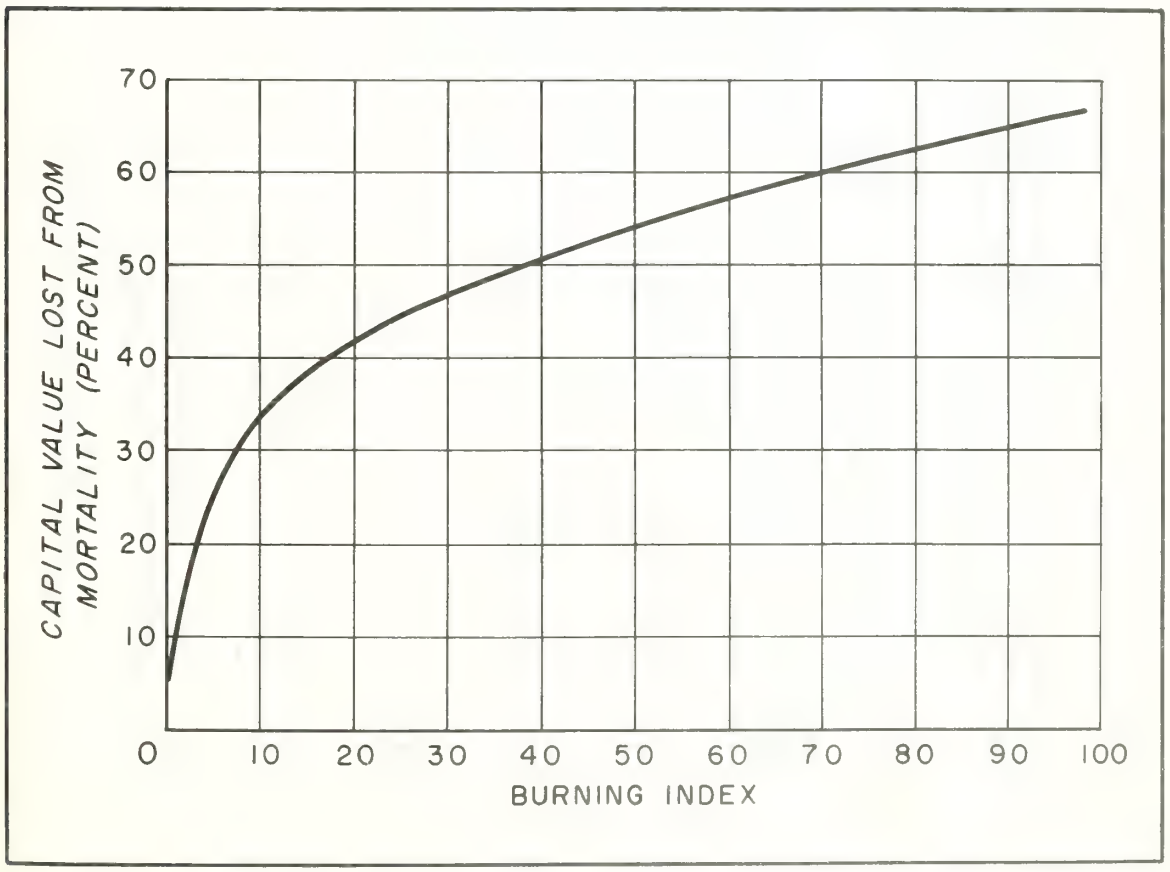

Figure 12.--Fire damage in young pine stands is correlated with burning index.

DANGER RATINGS AS A PARTIAL GUIDE TO AIR PATROL

Increasing use is being made of aircraft patrols in the South. Because of speed and versatility, they can save much effort in checking smokes to determine whether suppression action by ground forces is needed and in scouting the progress of large fires. Aircraft are also used to supplement tower detection during periods of low ground visibility and in various aspects of fire prevention and law enforcement.

A fire control manager needs guidelines to help him decide how best to budget flying time so as to buy the most protection for his money. Other things being equal, it can be assumed that air patrols should be made on days and during hours when the probability of fire occurrence is greatest. As has been indicated in earlier parts of this paper, there is a positive relation between burning index and fire occurrence; that is, as the index increases, the probability of fires also increases.

A method (9) for developing the use of burning indexes as partial guides to aircraft patrol is illustrated in table 4. In column (1) days were arranged according to burning index, cumulated upward in column (2), and percents were calculated in column (3). For purposes of this analysis, a 5-month period, January through April and December, was selected because these were the most severe months. The whole year or a combination of other months could, of course, have been used as desired; the procedure would have been the same. Fires were similarly arranged in columns (4), (5), and (6).

Table 4.--Relation between number and percent of patrol days and fires and burning index for the period January through April and December, 1959. Data are for a protection unit in a Southern State

Burning index	Days	Days cumulated	Days	Fires	Fires cumulated	Fires	Fires adjusted
	Number	Number	Percent	Number	Number	Percent	Percent
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
1	26	151	100	8	509	100	76
2	8	125	83	3	501	98	74
3	9	117	77	11	498	98	74
4	12	108	72	47	487	96	73
5	11	96	64	52	440	86	65
6	11	85	56	66	388	76	58
7	7	74	49	20	322	63	48
8	9	67	44	34	302	59	45
9	4	58	38	42	268	53	40
10	4	54	36	18	226	44	33
11	5	50	33	27	208	41	31
12	5	45	30	49	181	36	27
13	3	40	26	15	132	26	20
14	4	37	25	8	117	23	17
15	2	33	22	3	109	21	16
16	6	31	21	34	106	21	16
17	2	25	17	8	72	14	11
20	7	23	15	24	64	13	10
25	11	16	11	34	40	8	6
30	3	5	3	4	6	1	1
35	2	2	1	2	2	0.4	0.3

The next step was to determine the percent of fires by hour of origin and to consider the number of hours that a pilot and observer could fly without undue fatigue. Five hours were taken to be a reasonable stint and the period from noon to 5 p.m. proved to have the greatest concentration (76 percent) of the fires. The values in column (6) were accordingly multiplied by 0.76 to give adjusted values in column (7).

From table 4 it is possible to compare different percents of patrol days with regard to number of fires that occurred and burning index. For example, had patrols been made on about half of the days (49 percent, column (3)), flying would have had to be done on all days having a burning index of 7 or more. On these days, and between noon and 5 p.m., about half the fires (48 percent, column (7)) occurred and would theoretically have been observable.

Factors other than the probability of fire occurrence must, of course, be considered by the fire control manager in deciding when and where air patrols should be made. These include budget limitations, low ground visibility, probability of increased activity by potential fire starters, hot spots or blind areas, and values at stake.

Analyses such as described must be made of several years of records before a reasonably satisfactory operations guide can be developed.

FIRE-WEATHER FORECAST SERVICES

Little mention has so far been made of the excellent services provided by U. S. Weather Bureau fire-weather forecasters. The field man may be fully aware of the severity of today's burning conditions, but he has little basis for estimating tomorrow's conditions except as he may have access to fire-weather forecasts.

Four fire-weather forecast centers have been established in the East and South. These are: Boston, Massachusetts; Asheville, North Carolina; Macon, Georgia; and Tallahassee, Florida. Although routinely issued forecasts are of necessity for fairly large geographic areas, forecasts can be pinpointed if fire control men so request. If emergency conditions exist, or in the event of a project fire, special forecasts will be prepared at any time provided the forecaster is informed as to specific weather information wanted for a specific area.

The following is a brief summary of procedures followed by the Asheville center. Other centers may have somewhat different routines. Facsimile weather maps of surface and upper air conditions arrive periodically during the day from the National Weather Analysis Center in Washington, D. C. These are supplemented by synopses of weather conditions and guidance forecasts by teletype from the National Weather Analysis Center and from a number of forecasting centers. Pilot balloon observations are received every six hours and radiosonde data at 12-hour intervals. During fire seasons, fire danger

measurements are received from approximately 100 selected danger stations, operated by state and federal agencies in a 6-state area, at about 2 p.m. by telegraph or telephone. The forecaster thus has a wealth of weather information which must be digested and interpreted in terms that will be useful to fire control men.

In ordinary years the fire season extends from February 15 through May 15 and from October 15 through December 5. However, dates are altered as needed to meet unusual fire situations. During these seasons, daily forecasts from Monday through Saturday are issued at about noon for the afternoon, evening, and following day. On Monday, Wednesday, and Friday, four-day outlooks are issued that indicate the principal weather changes expected. A standby watch is on duty on Sunday from 6 a.m. to 6 p.m. Forecasts are transmitted by telegraph or telephone from Asheville to designated offices of using agencies who then distribute them to field units.

Items included in the forecast for the day are cloud cover, precipitation expected, minimum fuel moisture, maximum temperature, and maximum wind speed and direction at open-type danger stations. Forecasts for the night include cloud cover, indicated precipitation, minimum temperature, wind direction and lowest speed, and maximum fuel moisture. Other items of weather information are sometimes added, such as expected wind shifts and the probable time of shift. These forecasts enable the fire control man to set up weather information on his fire danger meter and so to determine the probable buildup and burning indexes for the period ahead.

Special forecasts are prepared whenever requested. Field men sometimes ask questions, such as: "Will the weather hold during the next 12 to 18 hours?" "Will conditions be favorable for backfiring tonight?" "Is a change in wind direction expected so that I will need to shift the crews?" Such questions are gladly answered by the forecaster to the best of his ability but he is not likely to be particularly pleased when services are requested during periods of high danger only after a fire burns out of control.

Limited forecasting services can be obtained from Weather Bureau offices in: Montgomery, Alabama; Jackson, Mississippi; Shreveport, Louisiana; Houston, Texas; Fort Smith, Arkansas; Little Rock, Arkansas; Baltimore, Maryland; Hartford, Connecticut; Harrisburg and Philadelphia, Pennsylvania; and Albany, New York. Strongly expanded services can be expected, if funds become available, as a result of a recent National plan developed jointly by the Weather Bureau and the Forest Service.

NEED FOR ACCURATE BASIC RECORDS

Previous sections of this paper have described the applications of fire danger measurements in a variety of fire control activities and have outlined methods of analysis. The writer cannot emphasize too strongly that the value of such analyses depends to a great extent on the accuracy of the basic data.

There is little purpose in a fire control agency spending time and money in locating stations and providing instruments if it is lax in training observers and following up on station operation and maintenance. We have found that there is no substitute for patient training of observers and periodic and thorough inspection of stations. These things are elementary, yet a substantial number of stations in the East and South are substandard and consequently have substandard records.

The criticism directed at inaccuracies in fire danger records apply equally well to fire reports. Number of fires and their dates and locations are probably reported with fair accuracy but acres burned, and particularly causes except for a few categories, are often questionable.

A NATIONAL FIRE DANGER SYSTEM

The desirability of having a National fire danger system rather than a number of regional systems has been recognized for many years. Work in earnest on the project was started in 1958 when a staff position was established in the Washington Office Division of Forest Fire Research in cooperation with the Division of Fire Control (5). Some of the objectives are to provide for better National coordination of fire control plans and more uniformity among planning systems, evaluation and comparison of work loads and allotment of funds, appraisal of fire control performance, and a more meaningful basis for reporting fires, area burned, damages, and expenditures. In addition, a National system will simplify the interpreting of fire danger when men are detailed or transferred from one region to another, and will facilitate better coordination and understanding among cooperating agencies.

Regardless of how weather variables may be integrated with fire phenomena in a National system, the principles of analyzing fire occurrence and behavior under a variety of fire climates will remain the same. The application of these principles should make possible a much better evaluation and comparison of fire problems and progress among regions and provide additional tools for fire control planning on a National scale.

Agriculture Asheville

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Station Paper No. 130 September 1961

WHITE PINE EMERGENCE TIPBURN. A PHYSIOGENIC DISTURBANCE

by

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INTRODUCTION

Emergence tipburn, a needle blight of eastern white pine, Pinus strobus L., has occurred from time to time throughout the normal range of that species. This blight, also called white pine blight and white pine needle dieback, is characterized by a dying of the tips of the new elongating needles in June or July. Although absolute proof is not yet available, it now appears that the causal factor is atmospheric and environmental in nature. This paper presents the results of some of the investigations of the disease and some new evidence that naturally occurring ozone is a likely causal agent.

The disease was first described by Dana in 1908 (2) and again by Spaulding in 1909 (12). Faull (3) determined that most of the absorbing roots of diseased trees were dead, but he was unable to determine the cause of root mortality. He also gave evidence that the disease was noncommunicable, when he failed to induce the disease in healthy branches by "fusing" them to diseased branches of affected trees.

Toole (14) was unable to prevent the occurrence of needle blight by weekly applications of fungicide from the time new growth started until symptoms of the blight appeared in June. He was also unable to induce the disease by inoculations with needle fungi found associated with diseased trees.

Linzon (9) presented an excellent description of the development of the foliar symptoms, which he observed to be initiated on sunny days that immediately followed one or more days of wet weather. Linzon also reported on unpublished experiments of A. J. Riker and B. W. Dance, who found that needle-blighted scions grafted to healthy stocks exhibited foliar symptoms annually thereafter, while the healthy stocks remained unaffected. Linzon concluded that the disease is nonparasitic in etiology.

Hepting and Berry (8) listed and differentiated the various needle diseases that occur on white pine in the southern Appalachians. These diseases include: emergence tipburn; brown spot, caused by the fungus Scirrhia acicola; another fungus disease caused by Bifusella linearis which affects only 1- and 2-year-old needles; and what may be acute and chronic effects of air pollution. Renewed interest in emergence tipburn has occurred as a result of the confusion of symptoms of this disease with those possibly caused by air pollution, since white pine appears sensitive to both.

Measurements of oxidant have been made in unpolluted air by Harrison and Lodge (6). They recorded peaks as high as 38 p.p.h.m. (parts per hundred million) and found that on more than half of the days in question oxidant values remained at half the daily maximum or above for periods of time greater than 16 hours. Heggestad and Middleton (7) recorded a maximum concentration of ozone of 38 p.p.h.m. in registrations at Beltsville, Maryland, in 1958. On the day that this maximum occurred, concentrations ranged above 20 p.p.h.m. continuously for 3.3 hours.

INVESTIGATIONS

The investigations reported here include (1) studies of the root condition and the root fungus flora of diseased and healthy trees, (2) the effects of moving trees from a chronic tipburn area to an area seldom affected, (3) the effects of grafting diseased scions to healthy trees and vice versa, and (4) experiments and observations dealing specifically with ozone as a likely cause of emergence tipburn.

Root Aspects

In an attempt to determine the relation of root condition and root fungi to emergence tipburn, an examination of the roots of some diseased and healthy trees was carried out by two methods. In one method, carried out during the summer months, primary roots were traced as far toward the ends as possible in order to determine whether any root dieback had occurred. Next, in an investigation carried out during the winter, a block of soil known to contain feeder roots of the tree being examined was taken to the laboratory, where living and dead feeder roots were removed and examined. In this manner, root samples from 10 diseased and 10 healthy trees were examined. The trees selected for examination were growing in the Marlinton, West Virginia, area, where emergence tipburn is known to have been prevalent for the past several years.

Most roots could be followed to a diameter of approximately 0.06 inch before breaking from extraction. Seventy-two percent of the primary roots of diseased trees had dead ends, while only 28 percent of the primary roots of healthy trees had dead ends. Living extender tips were found on 57 percent of the primary roots of healthy trees, but only on 18 percent of the roots of diseased trees (table 1).

Sampling in two areas showed almost twice as high a percentage of feeder roots alive on healthy trees as on diseased trees (table 2).

Concurrent with the root examinations, several hundred fungus isolations were made. Primary isolations were made by placing surface-sterilized root pieces on water agar alone and on water agar containing Rose Bengal. Surface sterilization was accomplished by a brief dip in 3-percent hydrogen peroxide, or by washing overnight in running tap water. Attempts were made to isolate Phytophthora spp. from the rhizospheres of blighted and healthy trees by means of the Tucker apple technique as modified by Campbell (1).

Attempts to isolate Pythium spp. from the rhizospheres were carried out by means of the technique described by Sleeth (11). Twenty-seven fungus genera were identified (table 3). None of the isolates was a recognized root pathogen and none was associated only with diseased trees.

Table 1.--Mortality of primary roots on needle-tipburned and healthy white pines

Observation	Healthy trees		Diseased trees	
	Number	Percent	Number	Percent
Trees examined	7	--	8	--
Roots examined	7	--	11	--
Roots found with living extender tips	4	57	2	18
Living extender tips found	10	--	3	--
Roots with dead distal portions up to 0.12 inch in diameter	2	--	4	--
Roots with dead distal portions 0.12 to 0.25 inch in diameter	0	--	4	--
Total roots with dead distal portions	2	28	8	72

Table 2.--Mortality of feeder root tips on blighted and healthy white pines 1/

Area	Number of trees and condition	Root tips	
		Examined	Living
		Number	Percent
1	5 Healthy	75	61
1	5 Diseased	52	31
2	5 Healthy	67	51
2	5 Diseased	95	33

1/ The number of root tips examined in each category is the sum of root tips found on one root from each of five trees.

Table 3.--Fungi isolated from roots of needle-tipburned and healthy white pines

1. Trichoderma sp.
2. Penicillium spp.
3. Spicaria sp.
4. Cephalosporium sp.
5. Cladosporium sp.
6. Mucor sp.
7. Mucor ramannianus
8. Gliocladium sp.
9. Cunninghamella sp.
10. Mortierella pusilla
11. Mortierella vinacea
12. Zygorhynchus sp.
13. Arthrobotrys sp.
14. Chaetomium globosum
15. Sporotrichum sp.
16. Didymostilbe sp.
17. Helicostylum sp.
18. Absidia sp.
19. Piptocephalis xenophila
20. Aspergillus niger
21. Aspergillus spp.
22. Hormiscium sp.
23. Alternaria sp.
24. Mycotypha microspora
25. Geotrichum sp.
26. Helminthosporium sp.
27. Leptographium sp.
28. Fusarium sp.
29. Pestalotia sp.
30. Pullularia pullulans

Transplanting

A transplanting experiment was carried out in December 1958 to determine whether diseased trees would recover when moved to an area of low disease incidence, and to check on earlier observations to the effect that transplanting alone appeared to reduce tipburn at least the following year. All seedlings used were susceptible as shown by typical tipburn symptoms on

1958 needles. Seedlings were obtained near Marlinton, West Virginia, and were transplanted as follows: One group was moved 225 miles south to an area near Asheville, North Carolina, where the disease had not been noted in recent years; one group was moved 20 miles south to a new location in the same general West Virginia area; a third group was dug up and immediately replaced in the same hole. Check trees were left undisturbed.

A total of 44 blighted trees were used in the transplanting experiment, 41 of which have survived (table 4). During the first summer following transplanting, only 25 percent of the trees that were either dug up and replanted in the same spot, or transplanted a short distance away, were blighted. This apparent resistance lasted only one season, however, since during the second season all of the trees that had been dug up and replanted in the same spot were again blighted, and 60 percent of the trees moved only a short distance were blighted. Of the trees moved to North Carolina, 72 percent were blighted during the first year following transplanting when a mild attack of emergence tipburn occurred there, but none was blighted the second year. Blight on the undisturbed checks recurred both years of the experiment. These results indicated a persistent condition in the West Virginia area, conducive to tipburn and not apparently related to a pathogen or to soil or soil moisture.

Table 4.--Transplanting of needle-tipburned trees

Treatment	Trees treated	Number of trees with needle tipburn		
		Before transplanting, 1958	1 year after transplanting, 1959	2 years after transplanting, 1960
		Number		
Checks, undisturbed	10	10	10	10
Checks, dug up but replanted in same spot	10	10	4	10
Transplanted, 20 miles south of origin	10	10	1	6
Transplanted, 225 miles southwest to North Carolina	11	11	8	0

Grafting

In order to investigate the possibility that a virus might be the causal agent, and to attempt to localize the pathology of emergence tipburn, a series of grafts was made during the spring of 1958. In this experiment, all combinations of diseased and healthy scions were joined by means of side cleft grafts to diseased and healthy stocks.

Results of the grafting experiment show that most scions taken from healthy trees continue to be healthy even when grafted to diseased trees, and most scions taken from diseased trees continue to be diseased each year following grafting, regardless of the condition of the root stock (table 5). None

of the root stocks appeared affected by the scions grafted to them, indicating that a virus is not likely to be involved. Of the 70 grafts made, 44 have survived. Forty, or 91 percent, of those surviving have persisted in their original condition. Thus emergence tipburn seems related little if any to the condition of the stock.

Table 5.--Summary of results of grafting experiment

Tree number	Type of graft	Grafts made	Grafts surviving	Persistence of surviving grafts 1/			
				1959		1960	
		Number	Number	Number	Percent	Number	Percent
7	Diseased scion, healthy stock	15	9	6	66	8	89
8	Diseased scion, healthy stock	10	7	4	57	6	86
9	Healthy scion, diseased stock	10	7	6	86	6	86
10	Healthy scion, diseased stock	15	5	5	100	5	100
11	Diseased scion, diseased stock	10	6	6	100	5	83
12	Healthy scion, healthy stock	10	10	10	100	10	100
Total		70	44	37	84	40	91

1/ Persistence refers to the characteristic of retaining the condition of tipburned or healthy that a scion possessed when grafted.

Atmospheric Aspects

For reasons brought out in the discussion, the cause of emergence tipburn has recently been considered to be atmospheric and gaseous in nature. Naturally occurring ozone seemed a likely causal agent.

A preliminary test of the hypothesis that ozone might be the cause of emergence tipburn was made by artificially ozonating several grafted ramets. Ozone for this test was generated by three General Electric G4S11 bulbs and recirculated by means of a small electric blower in a closed plastic bag. Ramets for the experiment were obtained by grafting scion material from a single field-susceptible tree and a single resistant tree to random nursery-grown seedlings. Several of these plants were exposed for 2-hour periods in the plastic bag, where ozone concentrations remained at about 10 p.p.h.m. Ozone concentrations were determined by means of the Mast Ozone Recorder with the air sample tube inserted into the bag.

Typical emergence tipburn symptoms began to appear about 48 hours following ozonation of the graft ramets taken from field-susceptible trees. Symptom development closely followed Linzon's description (9), starting with pink spots on one or both of the stomata-bearing faces some distance back

from the tip of the needle. The spots soon enlarged into pink bands and a gradual dying of the distal part of the needle followed, with the dead part sharply distinct from the green base. The dead tips were at first pinkish yellow, but after several days the color deepened to a brownish red. Resistant ramets were not affected by the ozonations.

DISCUSSION

It is not unusual for the branches and roots of eastern white pine trees affected with emergence tipburn to be intermingled with those of unaffected trees. Many trees under observation have never been tipburned, regardless of the severity of attack on neighbors. The response of trees to the factors causing tipburn appears clearly genetic, as suggested by Linzon (9). Varying degrees of tipburn injury among susceptible trees indicate that several genetic factors may be involved.

The failure to implicate a root pathogen and the tendency of conifers to suffer root dieback following loss of foliage strongly suggest that the root mortality observed occurs as a result of foliage injury. This has been shown for other species following insect defoliation, by Graham (5), Redmond (10), and Stillwell (13).

The persistence of healthy scions in remaining healthy when grafted to a diseased root stock and the persistence of diseased scions in remaining diseased when grafted to a healthy root stock support the hypothesis that the causal factor of this tipburn is atmospheric.

The results of the transplanting experiment also indicate an atmospheric causal factor, since trees transplanted a short distance, and unmoved trees in West Virginia, were diseased in 1960, the second season following transplanting, while trees balled with their soil and transplanted 225 miles southwest to North Carolina were free of tipburn. If a pathogen were in the soil or on the roots, it would hardly have been destroyed by transplanting, especially since 8 of the 11 trees brought to Asheville, North Carolina, were diseased the first year following transplanting when a mild attack of emergence tipburn occurred there. Climate conditions vary greatly between the two areas, and severe attacks of the disease at Asheville are rare.

The apparent resistance sometimes shown by some susceptible seedlings during the first season following transplanting is not understood. Only 4 of the 10 trees that were dug up and immediately replanted in the same spot were blighted during the first year following treatment, yet all 10 of the undisturbed check trees were blighted.

Since typical symptoms can be produced artificially by ozone at concentrations well below those known to occur often in unpolluted air, ozone could be a principal cause of emergence tipburn. It is also significant that ramets produced with scion material from trees resistant to emergence tipburn were resistant to artificially produced ozone.

An unusually high incidence of emergence tipburn attacks occurred during 1961 in western North Carolina and surrounding states. A record number of inquiries about this condition were received at the Southeastern Forest Experiment Station starting June 22. The fact that this high incidence of tipburn occurred at the same time as a very high incidence of weather fleck of tobacco was recorded by North Carolina State College, taken with the ozonation results, suggests that the two diseases might be caused by the same or related factors. Ozone has been considered a probable cause of weather fleck since the work by Heggestad and Middleton (7).

Götz (4) states that annual average amounts of total ozone increase from 0.17 cm. at the equator to an "ozone belt" of 0.26 cm. at latitude 60° N. This suggests that higher concentrations of surface ozone would occur in the more northerly latitudes. The disease also seems more prevalent and more damaging in the northerly latitudes, being very common in the northeastern United States and Canada, and rare on white pine in Georgia.

Linzon's descriptions of the weather conditions before and during periods when he noted the initiation of disease symptoms indicate that a cold front had passed through the area just before disease symptoms appeared. Götz (4) relates high ozone to cold fronts in a manner consistent with Linzon's weather observations as related to tipburn.

SUMMARY

Emergence tipburn, a needle blight of eastern white pine (Pinus strobus L.), attacks young developing needles in early summer. Evidence indicating that the cause of emergence tipburn is atmospheric and environmental in nature is presented, and ozone is suggested as a likely causal agent. Root mortality is greater on diseased than healthy trees, but this is regarded as a result of the loss of foliage. Many fungi were isolated from the roots, but none was associated consistently with the disease and none was a recognized root pathogen. Diseased trees transplanted to an area of less disease severity were thereafter affected less than checks left in the area where the trees were obtained. Diseased and healthy scions were grafted to diseased and healthy stocks. Ninety-one percent of the surviving scions persisted in their original condition regardless of the condition of the trees they were grafted to. Typical disease symptoms were produced on susceptible ramets by artificially ozonating the plants at 10 p.p.h.m. for 2 hours. Ramets from a tree unaffected in the field were unaffected by the same treatment. Abnormally high incidence of emergence tipburn and tobacco weather fleck occurred in early summer in North Carolina in 1961, suggesting the two diseases are caused by the same or related factors.

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Agriculture Asheville

Station Paper No. 131 October 1961

Wind Directions for Prescribed Burning in Southeastern United States

by

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INTRODUCTION

Prescribed burning is now being used for many purposes in the Southeast, such as fuel reduction, control of undesirable hardwoods, seedbed preparation, and disease control. Ideal weather for these burns varies with the purpose of the burn, the quantity and type of available fuel, and stand conditions. Practicing foresters differ in opinion as to the best weather for many of these purposes and conditions. In some years, the best burning conditions for a specific purpose may occur so infrequently that it may be necessary to burn during less favorable conditions. For example, the consensus in Florida, Georgia, and probably over much of the Southeast is that fuel reduction burning is best with "... a cold, steady wind from the North after a winter rain." 2/ 3/ 4/ 5/ In many places a "steady" north wind is rare.

Wind is recognized as the most important weather variable to be considered when using fire in the woods. It is generally agreed that burning cannot be safely undertaken unless the wind persists from about the same direction for the entire period of the burn. Any material change in wind direction is undesirable and a change of 90° or more could be disastrous.

1/ The senior author is Fire Weather Forecaster, U. S. Weather Bureau, assigned to the Southern Forest Fire Laboratory, Southeastern Forest Experiment Station, U. S. Forest Service. The junior author is Meteorological Technician, Southern Forest Fire Laboratory.

2/ Bickford, C. A., and Newcomb, L. S. Prescribed burning in the Florida flatwoods. U. S. Forest Serv. Fire Control Notes 8(1): 17-23. 1947.

3/ Hartman, A. A. Fire as a tool in southern pine. In Trees. U. S. Dept. Agr. Yearbook 1949: 517-527. 1949.

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OBJECTIVE

This study was made to find out which wind directions are most likely to persist 6 hours or longer when other weather conditions are forecast as suitable for burning and the frequency of these wind directions by month and location.

PROCEDURE

It was assumed that daytime burning should begin by late morning and the decision to burn (based on current and forecast weather) must be made by about 10 a. m. The 10 a. m. wind direction was, therefore, taken as the initial direction, and directions for the following 6 hours were compared with the 10 a. m. direction. For nighttime burning, 6 p. m. wind was used as the initial direction.

Hourly weather observations for the period 1950 through 1959 were used from the following U. S. Weather Bureau Stations: Macon and Savannah, Georgia; Jacksonville and Tallahassee, Florida; and Florence, South Carolina (daytime only). Daytime data only for the period 1948 through 1954 were used from the stations at Valdosta, Georgia, and Fort Myers, Florida. Locations of all stations are shown in figure 1.

Because burning cannot readily be done when the humidity is high, days when the average humidity for the 6-hour period (following 10 a. m. or 6 p. m.) was 70 percent or higher were not considered. Days with rain during the 6-hour period were also excluded. Strong winds increase the difficulty of controlling fires, so those days when the maximum wind during the 6-hour period was 20 knots or higher were also omitted. In burning practice, a forecast of adverse weather would have eliminated most of these cases.

For each station, month, and initial wind direction (to 16 compass points), the remaining data were divided into three classes. The boundaries of these classes are illustrated in figure 2. Class A represents cases where the wind varied less than 34° from the initial direction during the 6 hours following 10 a. m. (or 6 p. m.). Class B represents cases where the wind varied 34° or more but less than 79° from the initial direction, and Class C represents cases where the wind varied 79° or more from the initial direction. The average monthly frequency for each class was plotted in wind rose form (see Appendix). The best and poorest wind directions, from a wind persistency point of view, are shown in general terms in tables 1 and 2.

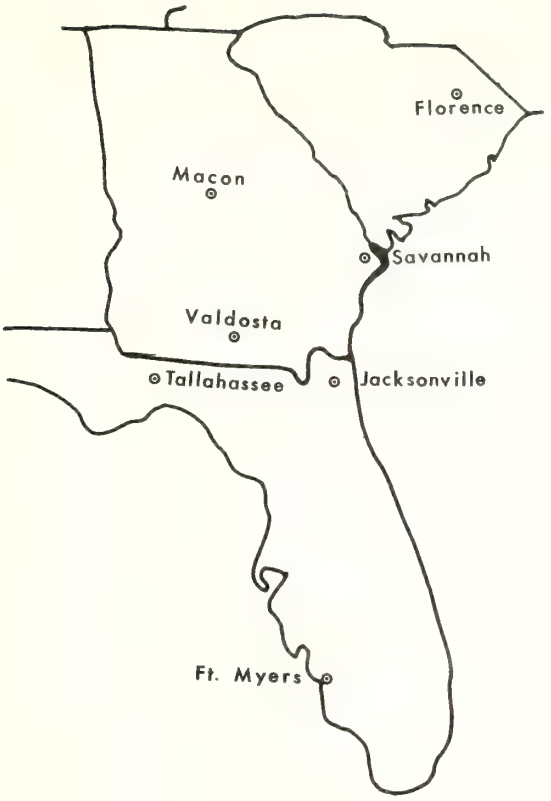


Figure 1.--Locations of stations used in this study.

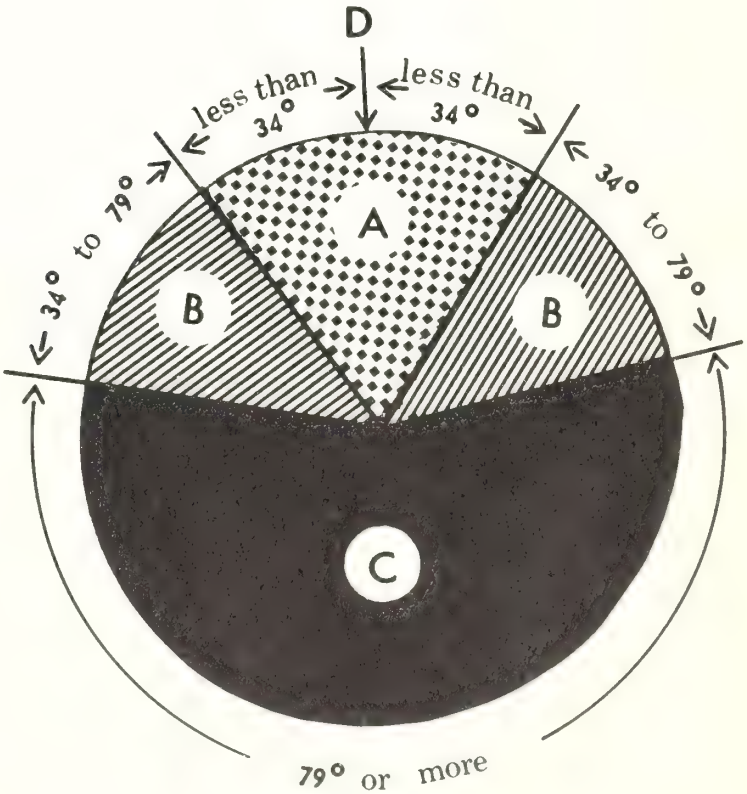


Figure 2.--Boundaries of the three classes in which data were divided. "A" wind persisted within 34° of initial direction "D," "B" wind varied 34° or more but less than 79°, and "C" wind varied 79° or more in the 6 hours following 10 a. m. or 6 p. m.

Table 1. --Best and poorest wind directions (from standpoint of wind persistency) for daytime prescribed burning by station and month, 1950 through 1959

Month	Type	Wind direction at observation stations						
		Florence, South Carolina	Macon, Georgia	Savannah, Georgia	Jacksonville, Florida	Valdosta, [1] Georgia	Tallahassee, Florida	Ft. Myers, [1] Florida
January	Best	SW'ly	Westerly	Westerly	Westerly	SW'ly	NW'ly	SE'ly [2]
	Poorest	SE'ly	Indeterminate	NE'ly	NE'ly	Easterly	Easterly	Indeterminate
February	Best	SW'ly	NW'ly	Westerly	Westerly	Westerly	Northerly	SE'ly [2]
	Poorest	NE'ly	Easterly	NE'ly	NE'ly	Easterly	Easterly	Easterly
March	Best	SW'ly	Westerly	Westerly	Westerly	SW'ly	NW'ly	SW'ly
	Poorest	Northerly	NE'ly	Northerly	Northerly	Easterly	Easterly	Easterly
April	Best	SW'ly	Westerly	Westerly	SE'ly	Westerly	NW'ly	SW'ly
	Poorest	Northerly	Easterly	SW'ly	Indeterminate	SE'ly	Easterly	Easterly
May	Best	SW'ly	Indeterminate	Westerly [2]	Easterly	SW'ly [2]	Southerly [2]	Westerly
	Poorest	Northerly	Indeterminate	SW'ly	SW'ly	Northerly	Easterly	Easterly
June	Best	SW'ly	Indeterminate	Westerly [2]	SE'ly [2]	Indeterminate	Indeterminate	Indeterminate
	Poorest	Northerly	Indeterminate	SW'ly	Westerly	NW'ly	Indeterminate	Indeterminate
July	Best	Southerly [2]	Indeterminate	Indeterminate	SE'ly	Indeterminate	Indeterminate	Indeterminate
	Poorest	Indeterminate	Indeterminate	SW'ly	SW'ly	Indeterminate	Indeterminate	SE'ly
August	Best	Indeterminate	Indeterminate	Easterly [2]	Easterly	Indeterminate	Indeterminate	SW'ly [2]
	Poorest	Indeterminate	Indeterminate	Westerly	Westerly	Indeterminate	Indeterminate	Easterly
September	Best	NE'ly	NE'ly [2]	NE'ly	Easterly	NE'ly	NE'ly [2]	Easterly [2]
	Poorest	SW'ly	Indeterminate	SW'ly	Westerly	Indeterminate	Indeterminate	Indeterminate
October	Best	NE'ly	NE'ly [2]	Easterly [2]	NE'ly	Easterly [2]	NE'ly	Easterly
	Poorest	NW'ly	Indeterminate	Northerly	NW'ly	Northerly	Indeterminate	Indeterminate
November	Best	SW'ly	NW'ly	Westerly	Westerly	Westerly	Northerly	Easterly [2]
	Poorest	NW'ly	Indeterminate	NE'ly	Northerly	NE'ly	Easterly	Indeterminate
December	Best	SW'ly	Westerly	Westerly	Westerly	NW'ly	Northerly	Easterly [2]
	Poorest	Indeterminate	Northerly	NE'ly	Northerly	Easterly	Easterly	Indeterminate

1/ Records for Valdosta, Georgia, and Fort Myers, Florida, cover period 1948 through 1954 only.
2/ Best direction, but still rather poor.

Table 2. --Best and poorest wind directions (from point of wind persistency) for nighttime prescribed burning by station and month, 1950 through 1959

Month	Type	Wind direction at observation stations			
		Macon, Georgia	Savannah, Georgia	Jacksonville, Florida	Tallahassee, Florida
January	Best	NW'ly	Westerly	Westerly	NW'ly
	Poorest	Southerly	Indeterminate	Indeterminate	Indeterminate
February	Best	Westerly	Westerly	Westerly	NW'ly
	Poorest	Indeterminate	Indeterminate	Indeterminate	Indeterminate
March	Best	NW'ly	Westerly	Westerly	NW'ly 1/
	Poorest	Indeterminate	Indeterminate	Easterly	Indeterminate
April	Best	NW'ly	Westerly	Westerly	NW'ly 1/
	Poorest	Indeterminate	Indeterminate	Easterly	Indeterminate
May	Best	NW'ly 1/	Indeterminate	SW'ly 1/	Indeterminate
	Poorest	Indeterminate	Westerly	SE'ly	Southerly
June	Best	Indeterminate	Indeterminate	Indeterminate	Indeterminate
	Poorest	Indeterminate	Indeterminate	SE'ly	Indeterminate
July	Best	Indeterminate	Indeterminate	Indeterminate	Indeterminate
	Poorest	Indeterminate	Indeterminate	SE'ly	Indeterminate
August	Best	Westerly 1/	Indeterminate	Indeterminate	Indeterminate
	Poorest	Indeterminate	Indeterminate	Indeterminate	Northerly
September	Best	NE'ly	NE'ly 1/	Indeterminate	NE'ly 1/
	Poorest	Indeterminate	Indeterminate	Indeterminate	Indeterminate
October	Best	NW'ly	NE'ly	Westerly	NE'ly
	Poorest	Easterly	Indeterminate	Indeterminate	Indeterminate
November	Best	Westerly	Westerly	Westerly	NW'ly
	Poorest	Indeterminate	Indeterminate	Indeterminate	Indeterminate
December	Best	Westerly	Westerly	Westerly	NW'ly
	Poorest	Indeterminate	Indeterminate	Indeterminate	Indeterminate

1/ Best direction, but still rather poor.

DISCUSSION OF RESULTS

For the coastal plain of Georgia, South Carolina, and northern Florida, a few general conclusions can be drawn:

1. During the winter burning season (December, January, February, and March), winds with a westerly component are more persistent than those with an easterly component.

2. In early autumn (September and October), northeasterly winds are most persistent, while November is a transitional month between the early autumn and winter regimes.

3. The other months are much less consistent, and in many areas favorable winds are so rare that burning may be impractical in the warmer months.

4. The more persistent nighttime wind directions are about the same as those in the daytime. Higher nighttime humidities, however, exclude many of the nights from consideration.

Data from more stations in south and central Florida are needed to determine if the Fort Myers results are applicable over any extended area.

For planning burns, the wind roses in the Appendix provide much more detailed information than tables 1 and 2, and the most persistent wind direction (dotted area persisted within 34° and hatched area varied between 34° and 79°) can be determined from them (fig. 3). If this direction also indicates a low number of days when the wind varied 79° or more (solid area), it is probably the safest one for burning. Before burning, however, check the latest fire weather forecast.

In some cases several directions are almost equally good. Landowners with large acreages to burn may want to plow lines in different directions on the various tracts to take advantage of each of these persisting winds.

Local terrain affects wind direction. It would probably be useful for landowners to record for some time the wind direction in the area they plan to burn and then compare these directions with those reported by the nearest U. S. Weather Bureau Office used in this study. If consistent differences are noted, it may be possible to adapt the data in the Appendix to reflect these differences. In hilly terrain and in coastal areas influenced by land and sea breezes, these differences are especially important.

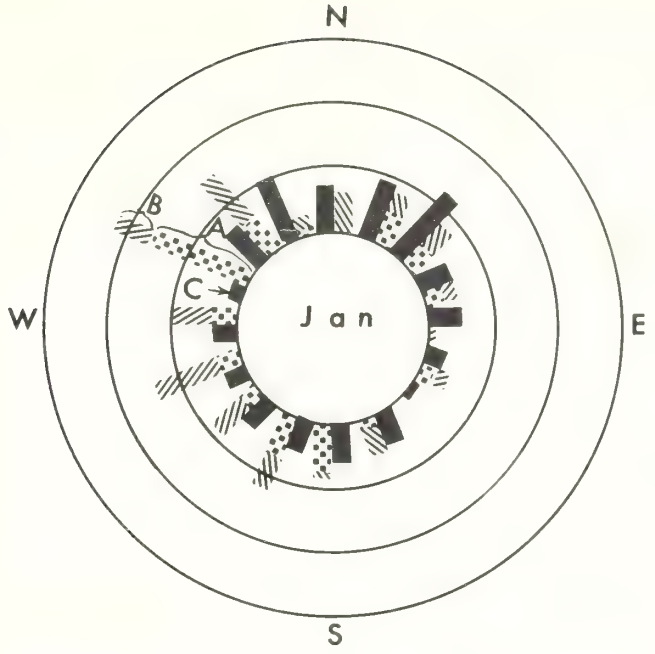


Figure 3.--Example of windrose reproduced from Appendix (Jacksonville, Florida, daytime, January).

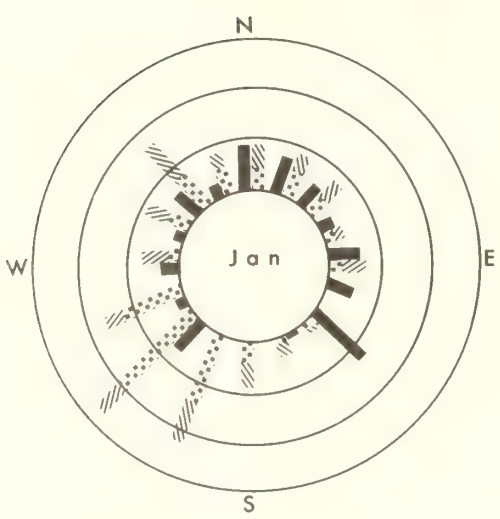
Appendix

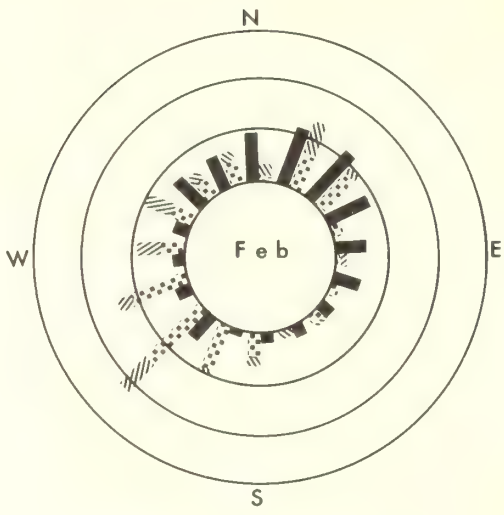
Wind roses for each month and station show the average number of days (distances between concentric circles represent one day) that the 10 a.m. wind (6 p.m. for nighttime data) persisted within 34° (dotted area), varied between 34° and 79° (hatched area), varied 79° or more (solid area) during the 6 hours after 10 a.m. (or 6 p.m.)

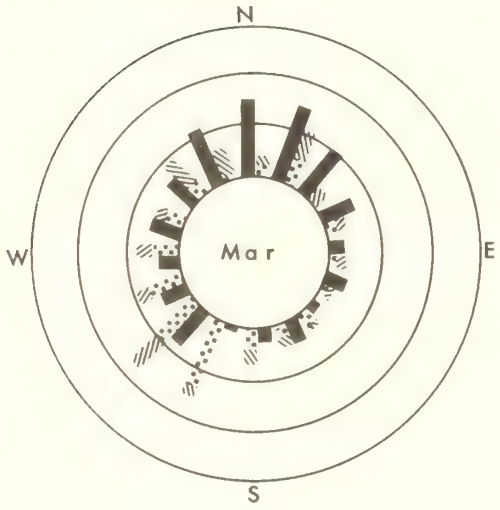
For example, the Jacksonville, Florida, (daytime) wind rose for January (fig. 3) indicates that a wind from the west-northwest is most persistent. An average of 1.6 days (A) had a west-northwest wind at 10 a.m. which persisted within 34° for 6 hours or longer. On an average of 0.6 day (B) the 10 a.m. wind from that direction varied between 34° and 79°, whereas an average of only 0.2 day (C) had 10 a.m. west-northwest winds that varied 79° or more. In general, all of the 10 a.m. directions from south-southeast clockwise through northwest persisted within 79° more frequently than they varied 79° or more.

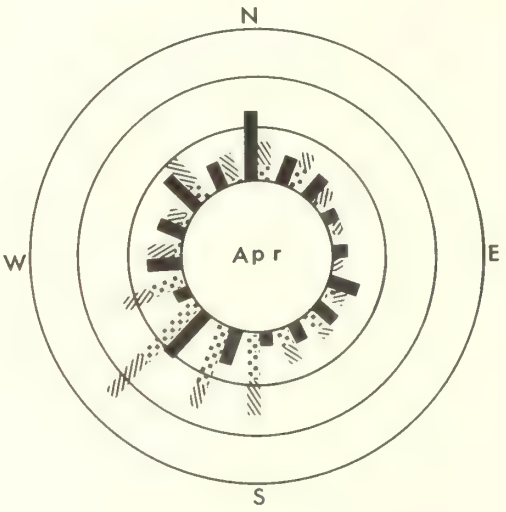
Wind rose data are for the 10-year period, 1950 through 1959, except data from Valdosta, Georgia, and Fort Myers, Florida, that are for a 7-year period, 1948 through 1954.

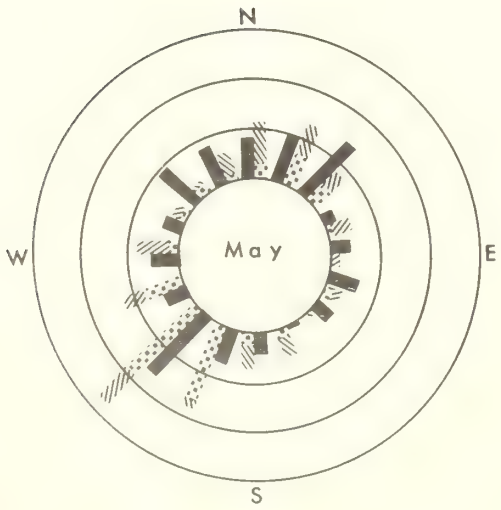
FLORENCE, SOUTH CAROLINA (daytime)

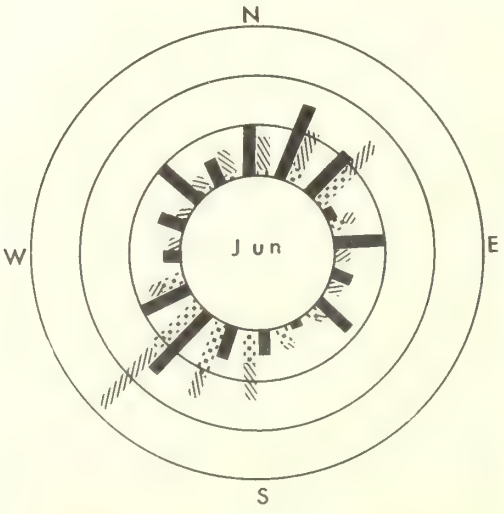




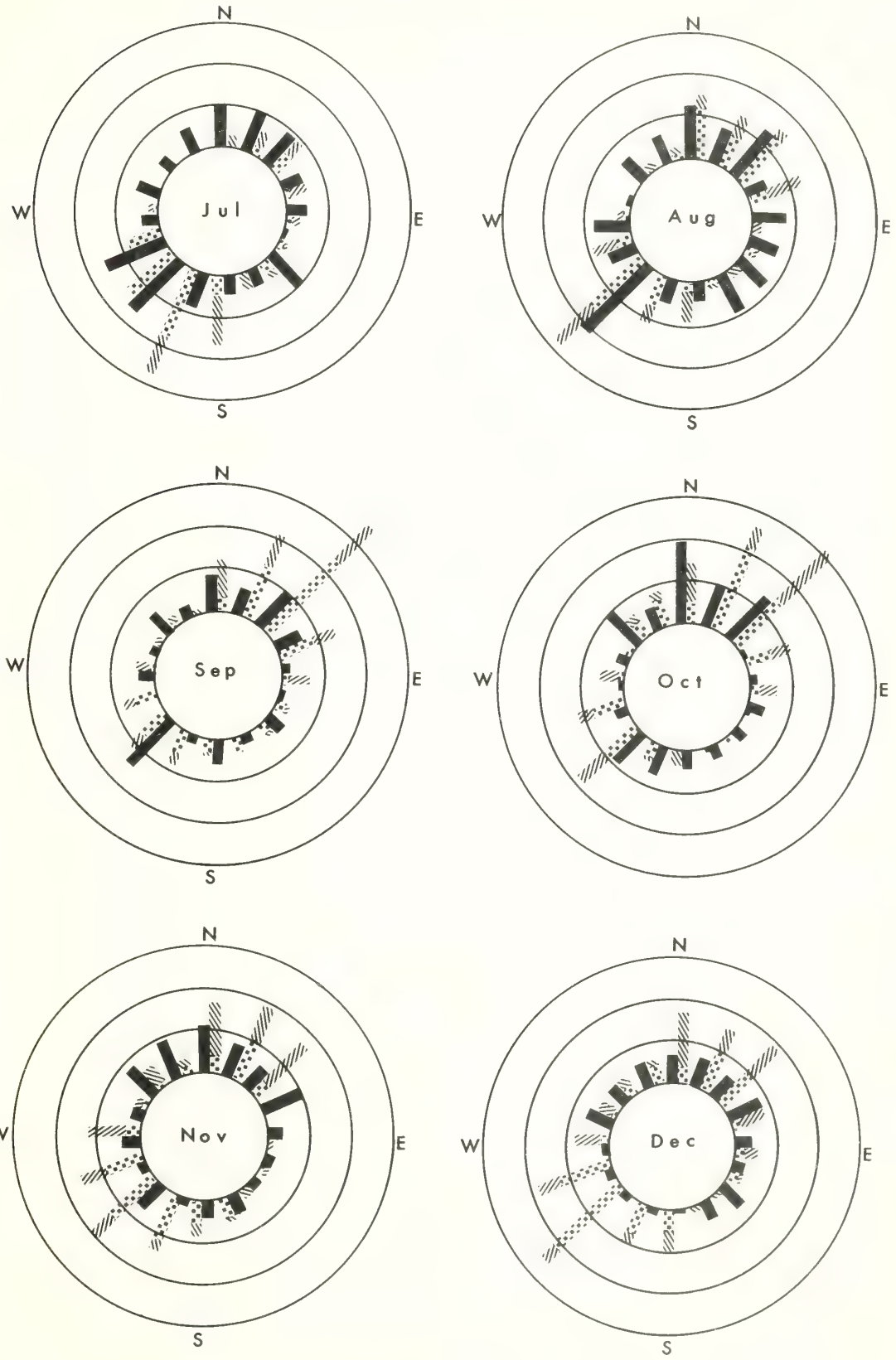




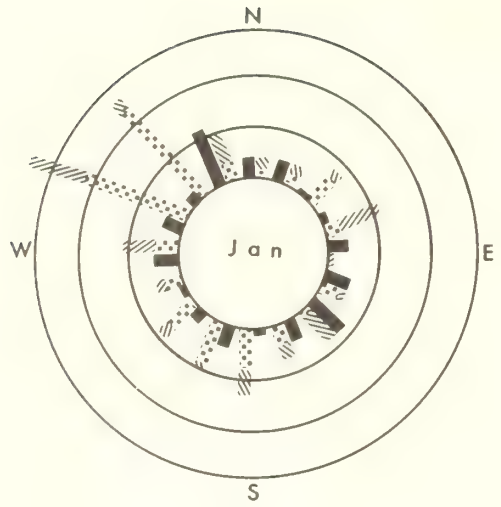


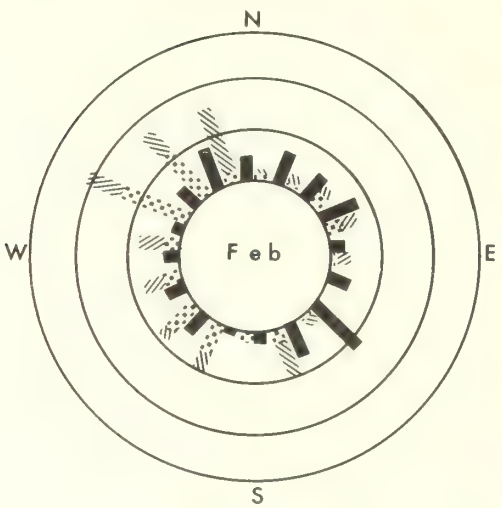


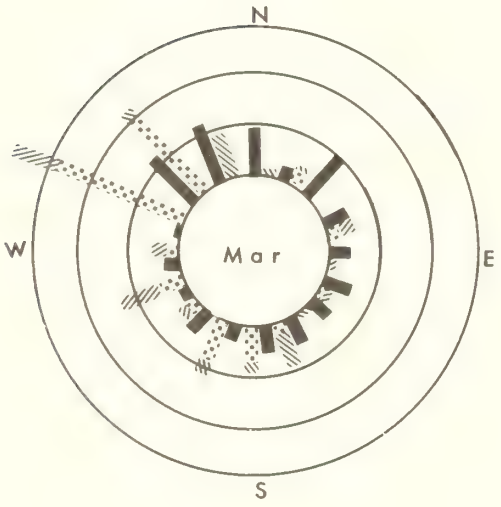
FLORENCE, SOUTH CAROLINA (daytime)

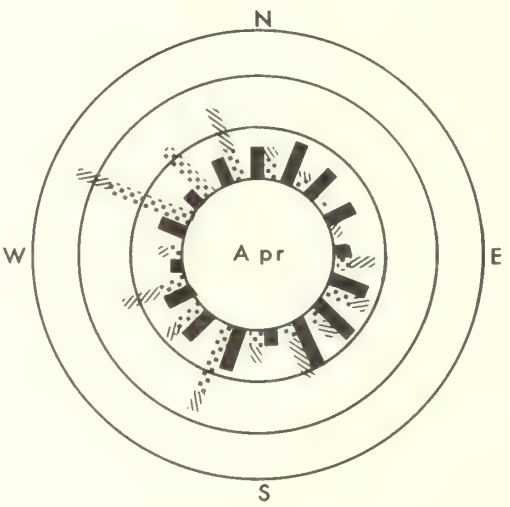


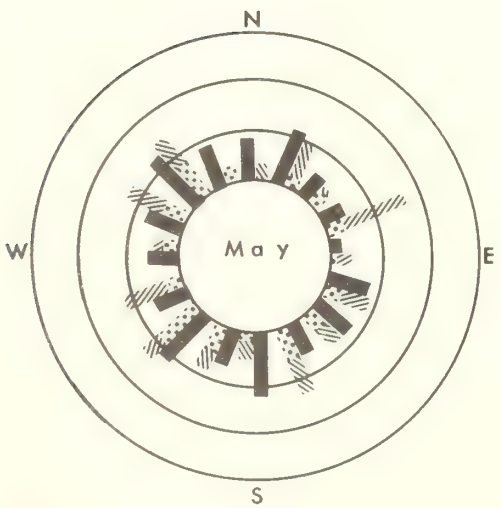
MACON, GEORGIA (daytime)

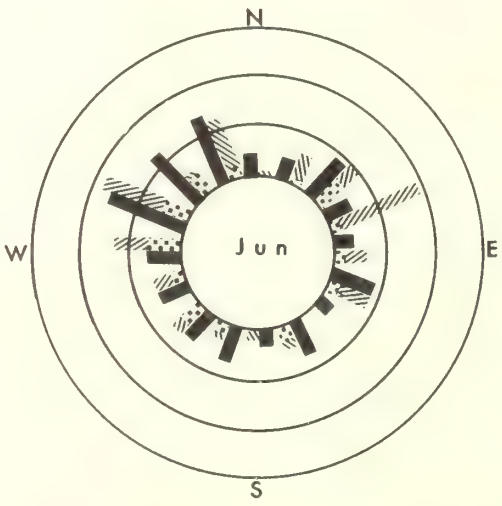




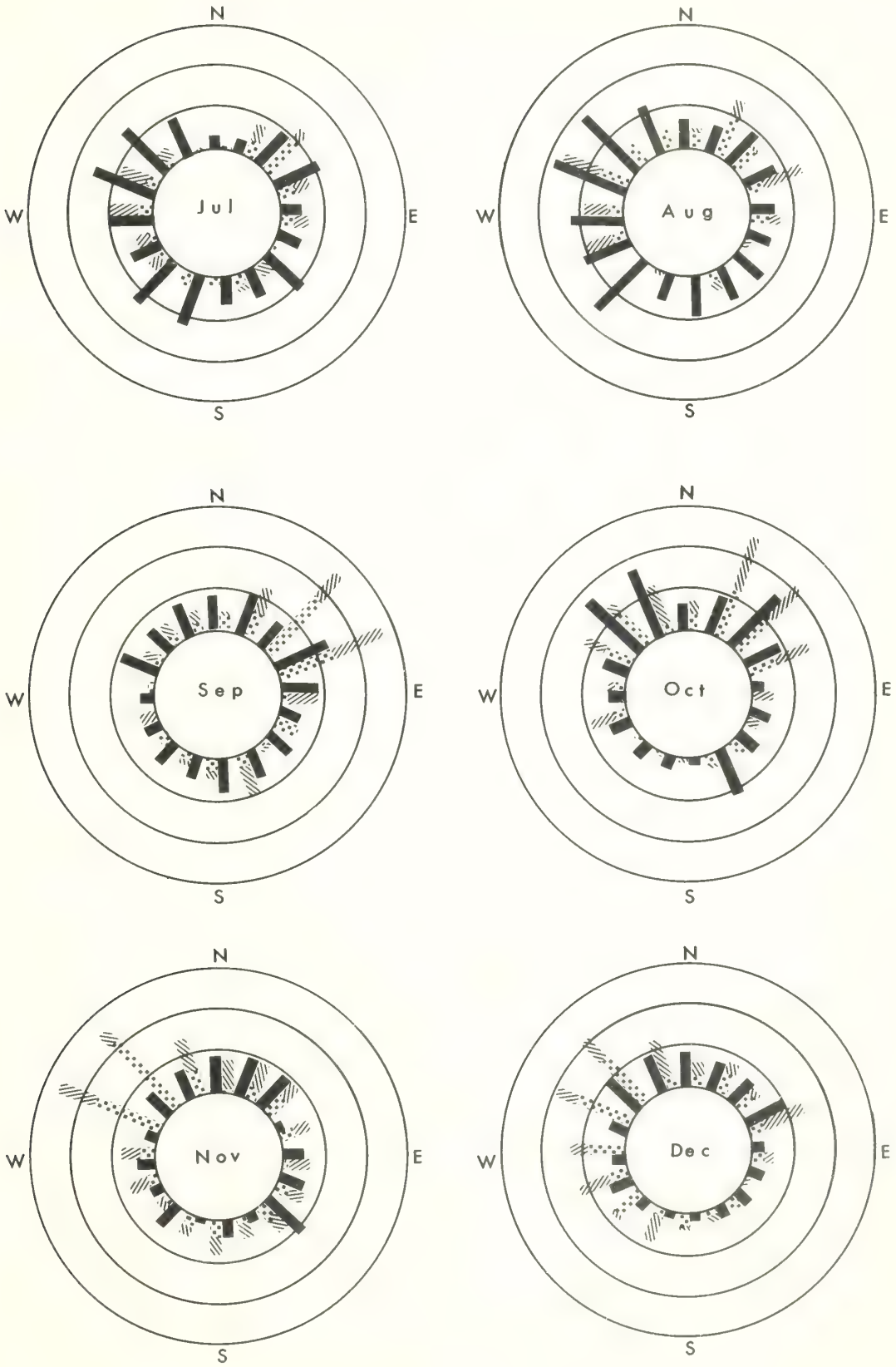




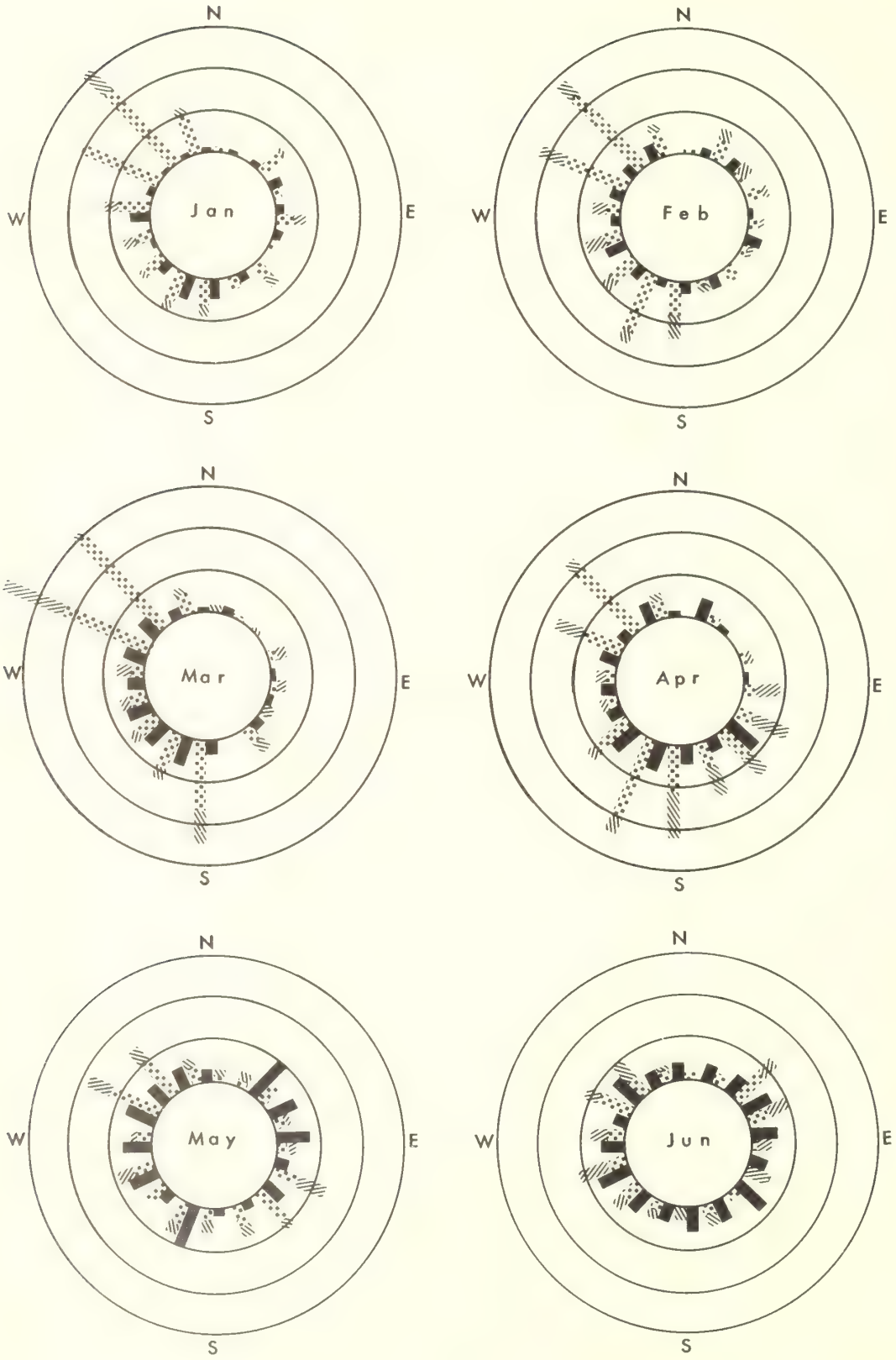




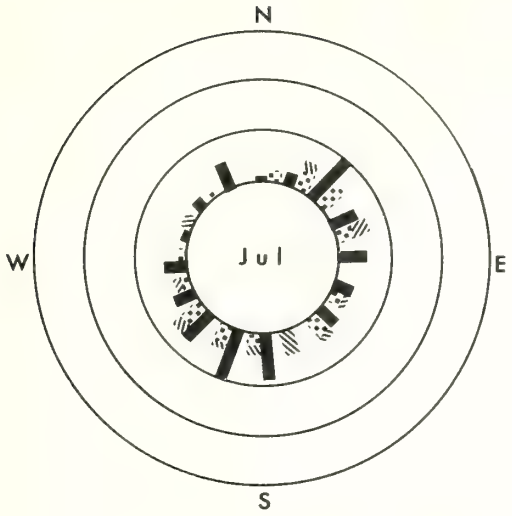
MACON, GEORGIA (daytime)

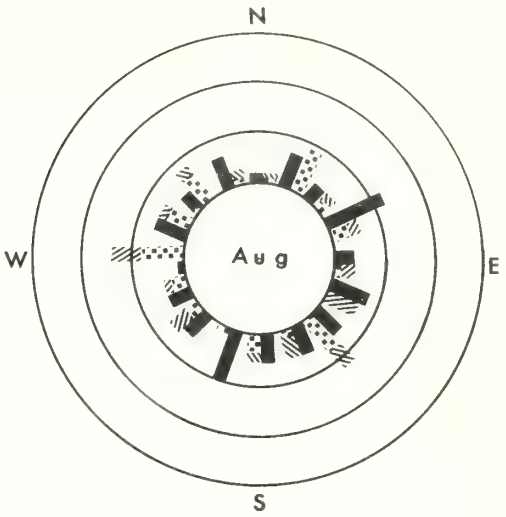


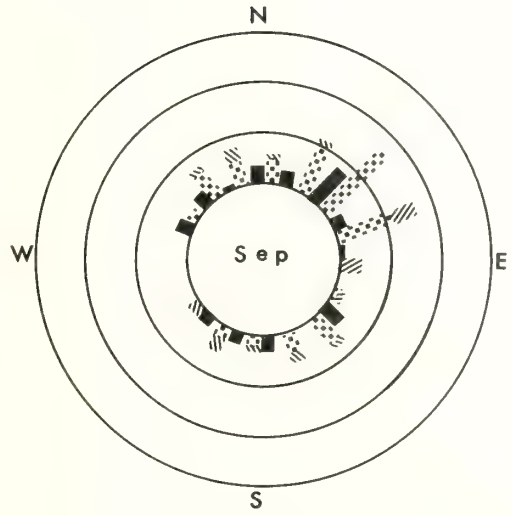
MACON, GEORGIA (nighttime)

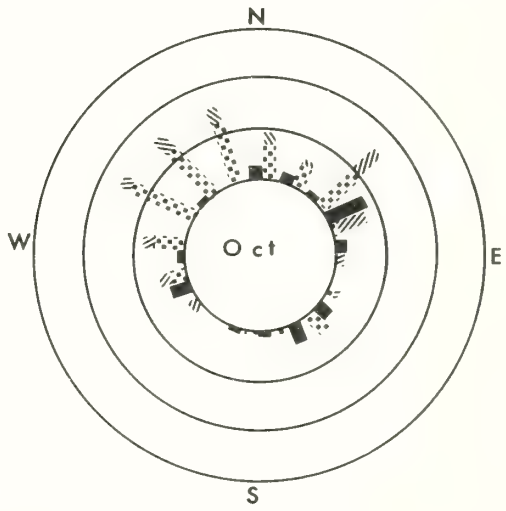


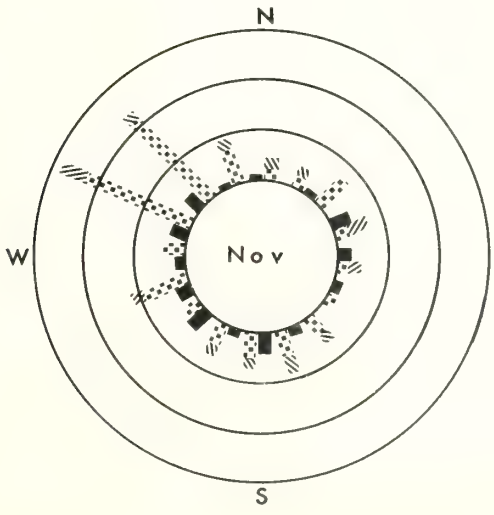
MACON, GEORGIA (nighttime)

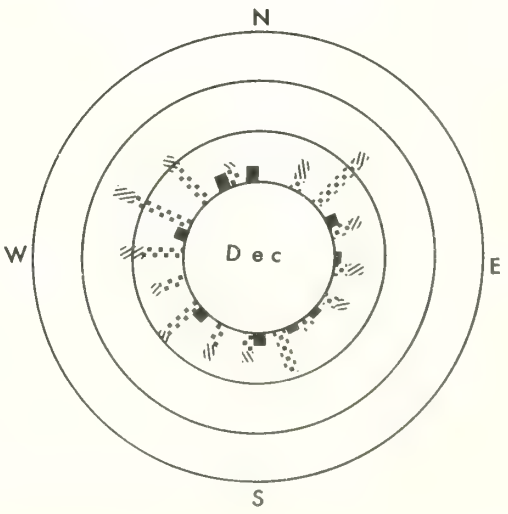




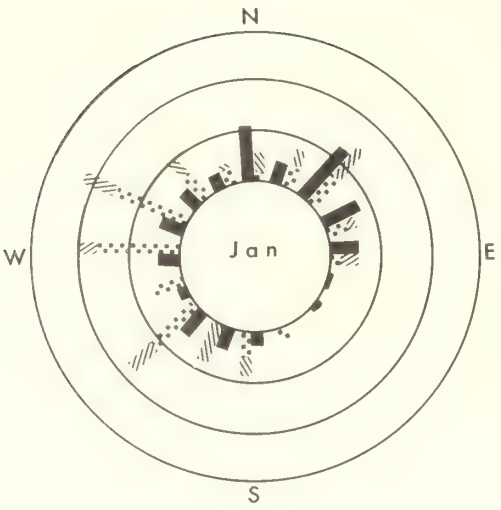


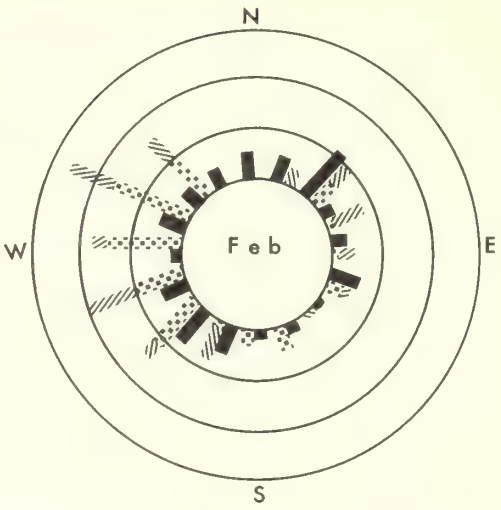


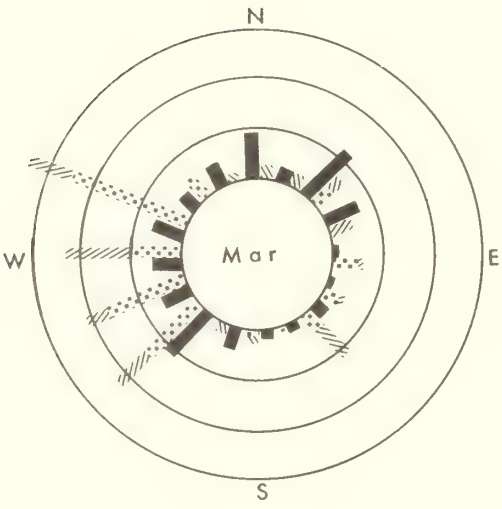


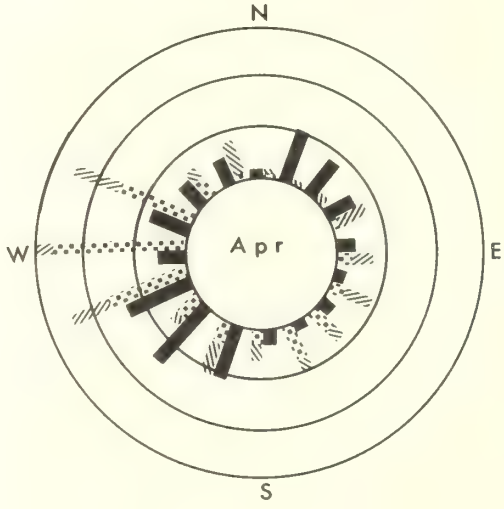


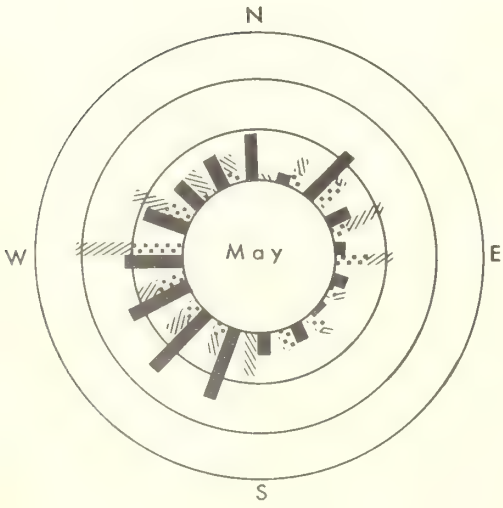
SAVANNAH, GEORGIA (daytime)

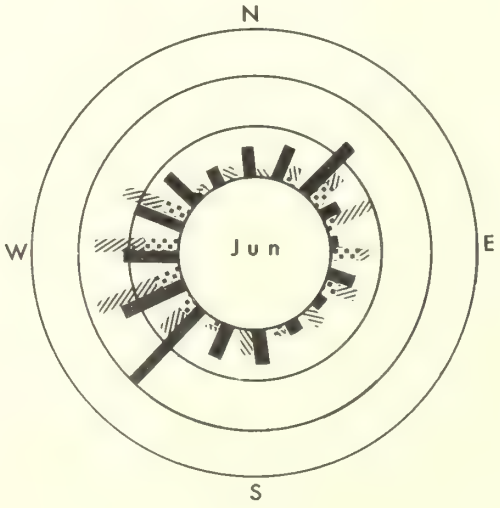




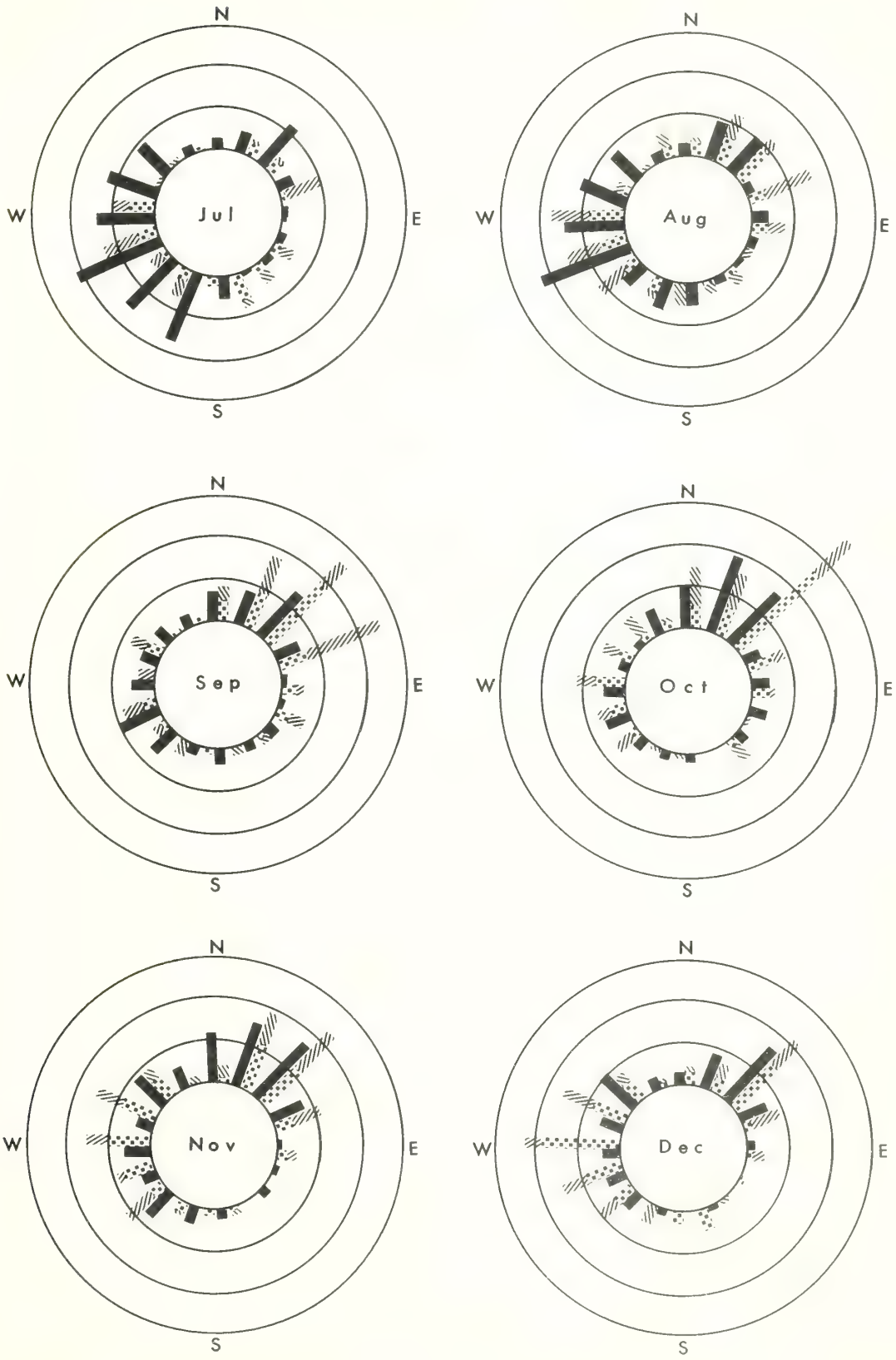




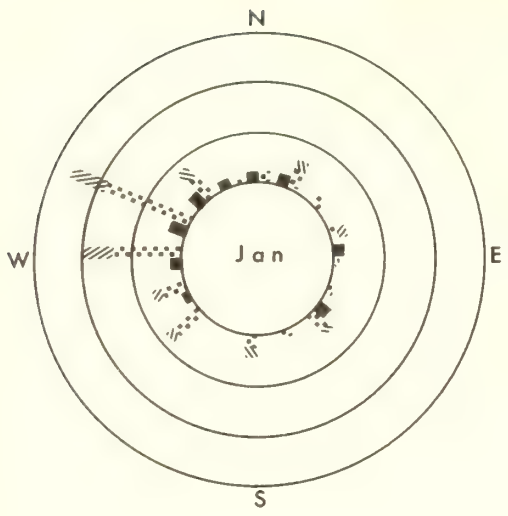


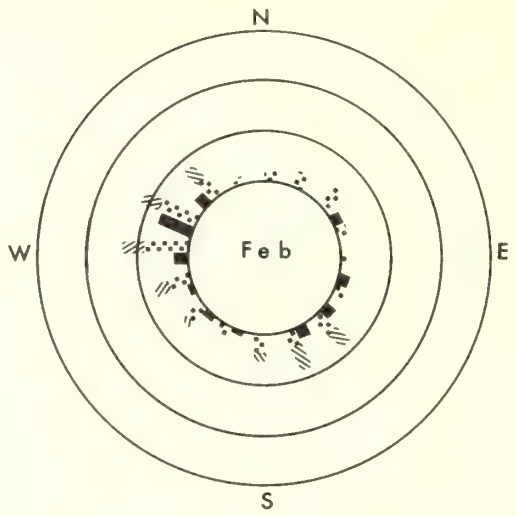


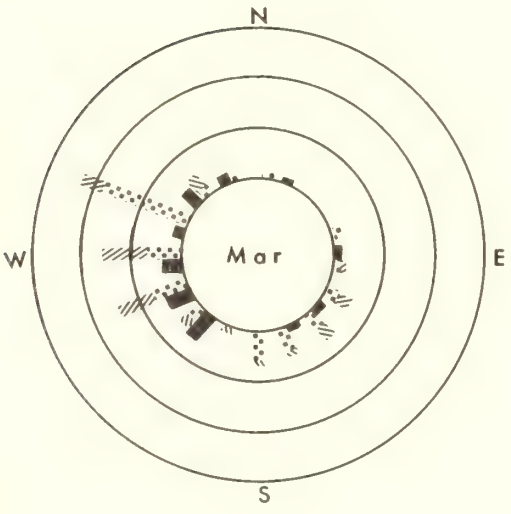
SAVANNAH, GEORGIA (daytime)

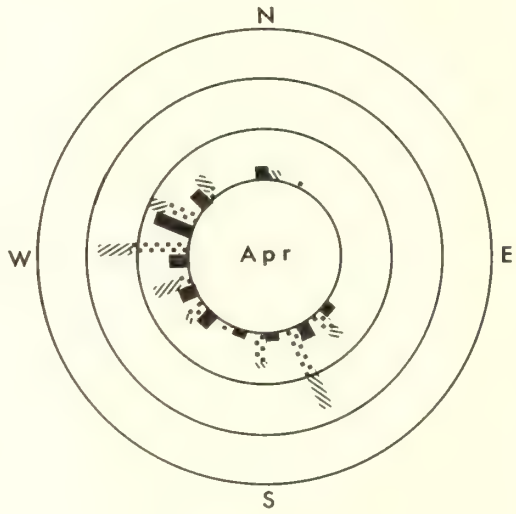


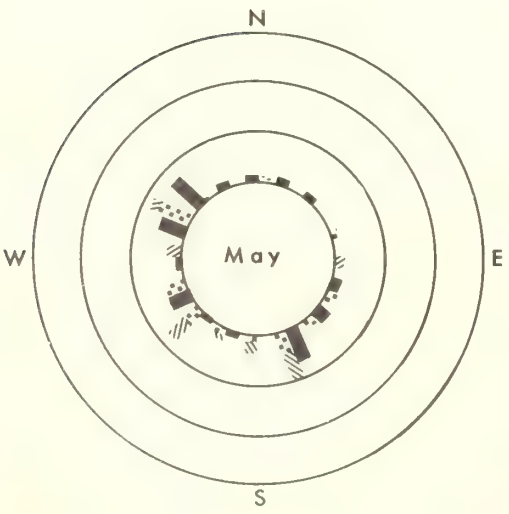
SAVANNAH, GEORGIA (nighttime)

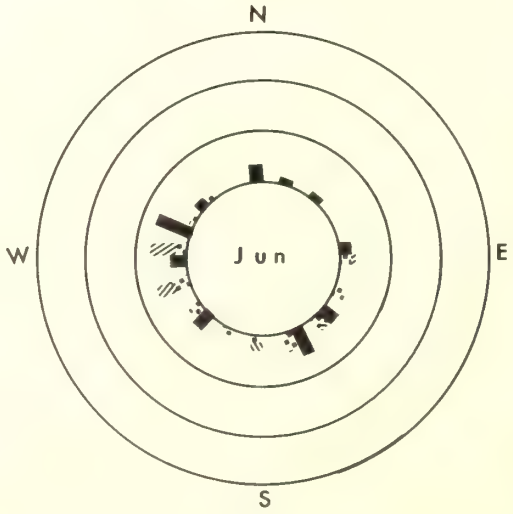




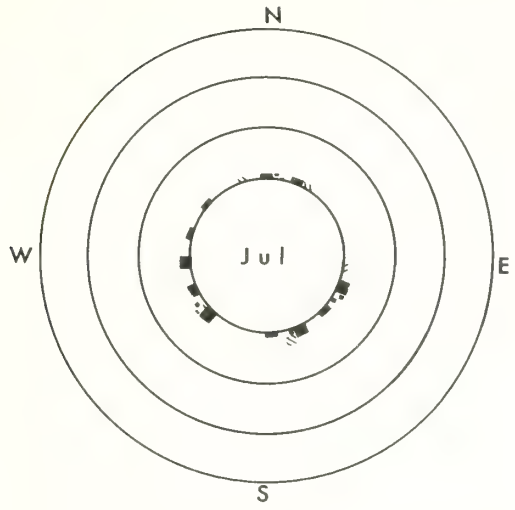


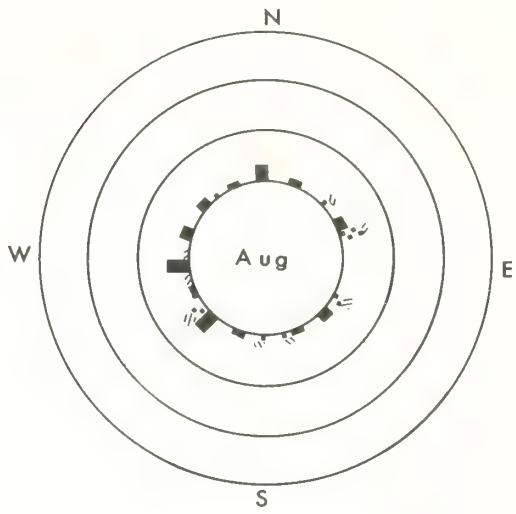


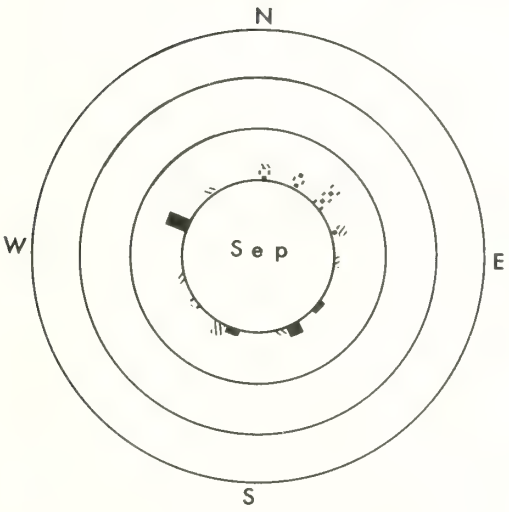


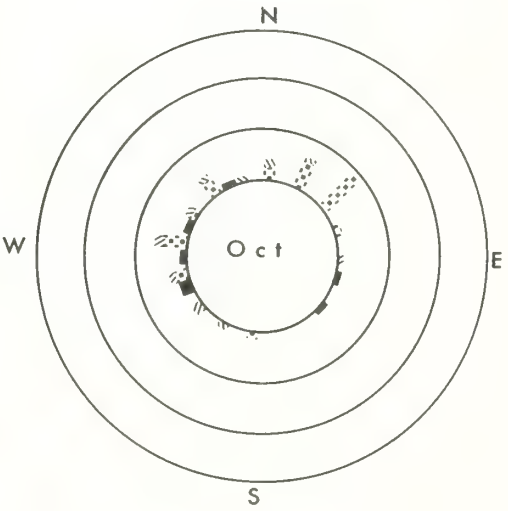


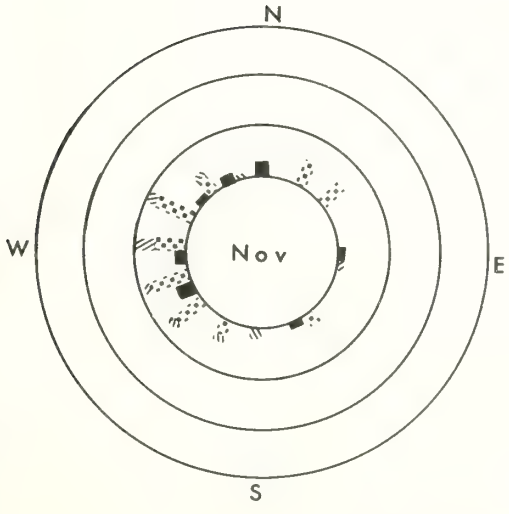
SAVANNAH, GEORGIA (nighttime)

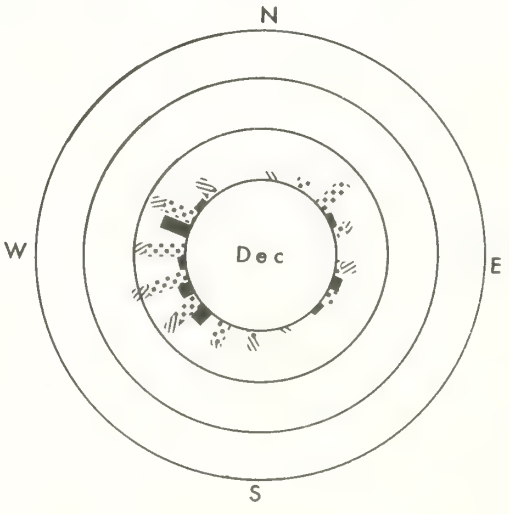




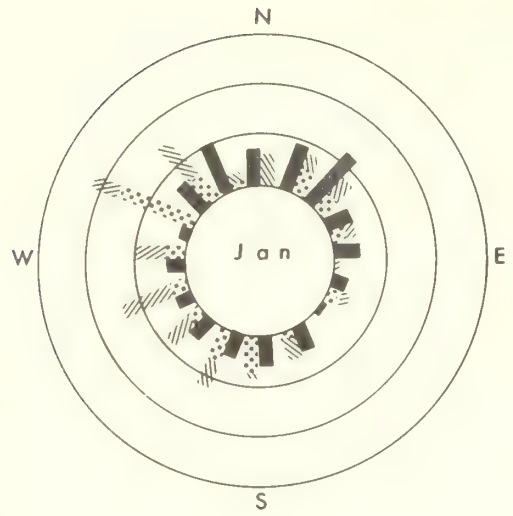


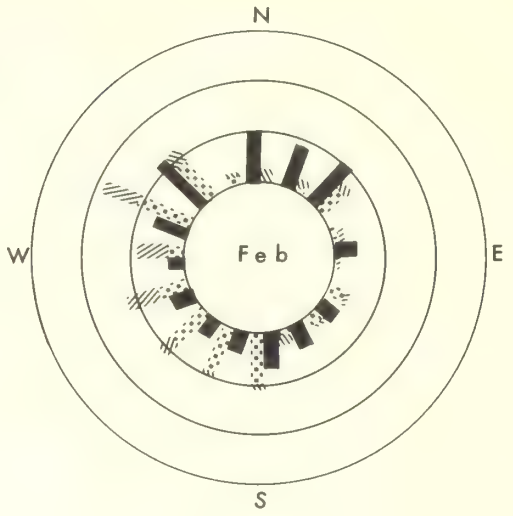


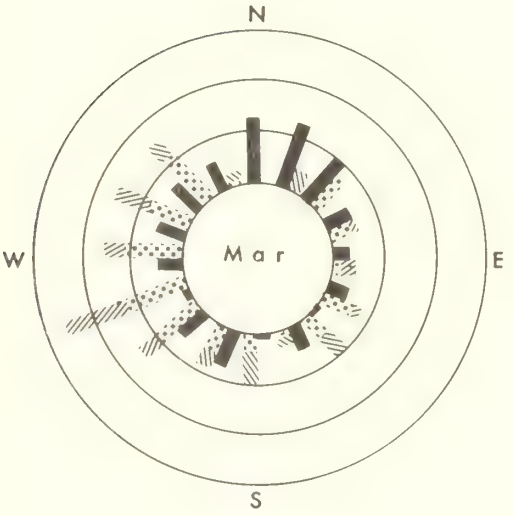


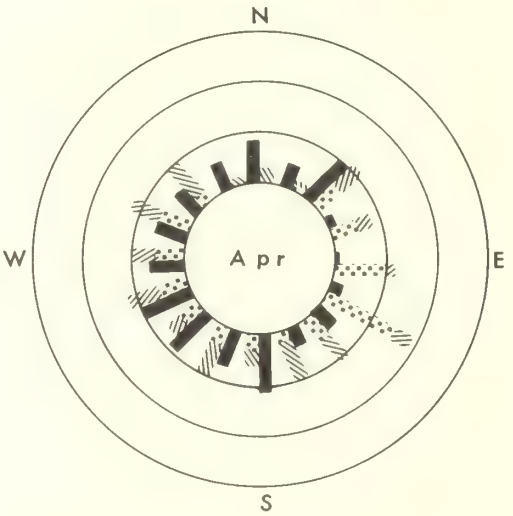


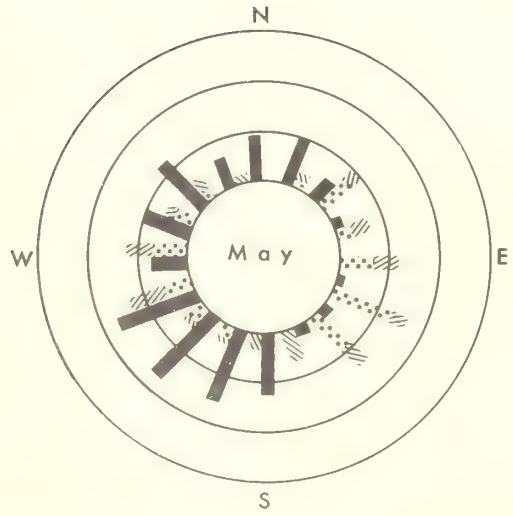
JACKSONVILLE, FLORIDA (daytime)

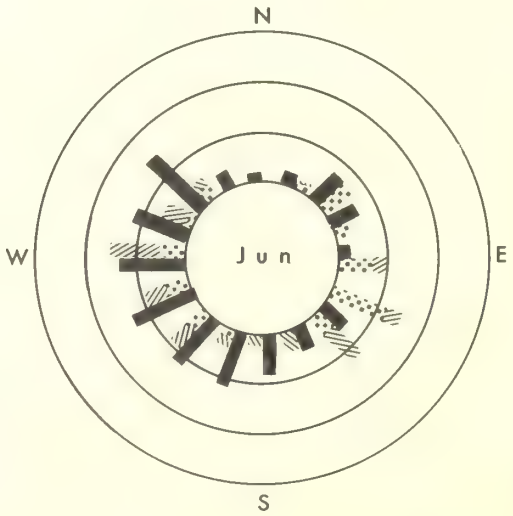




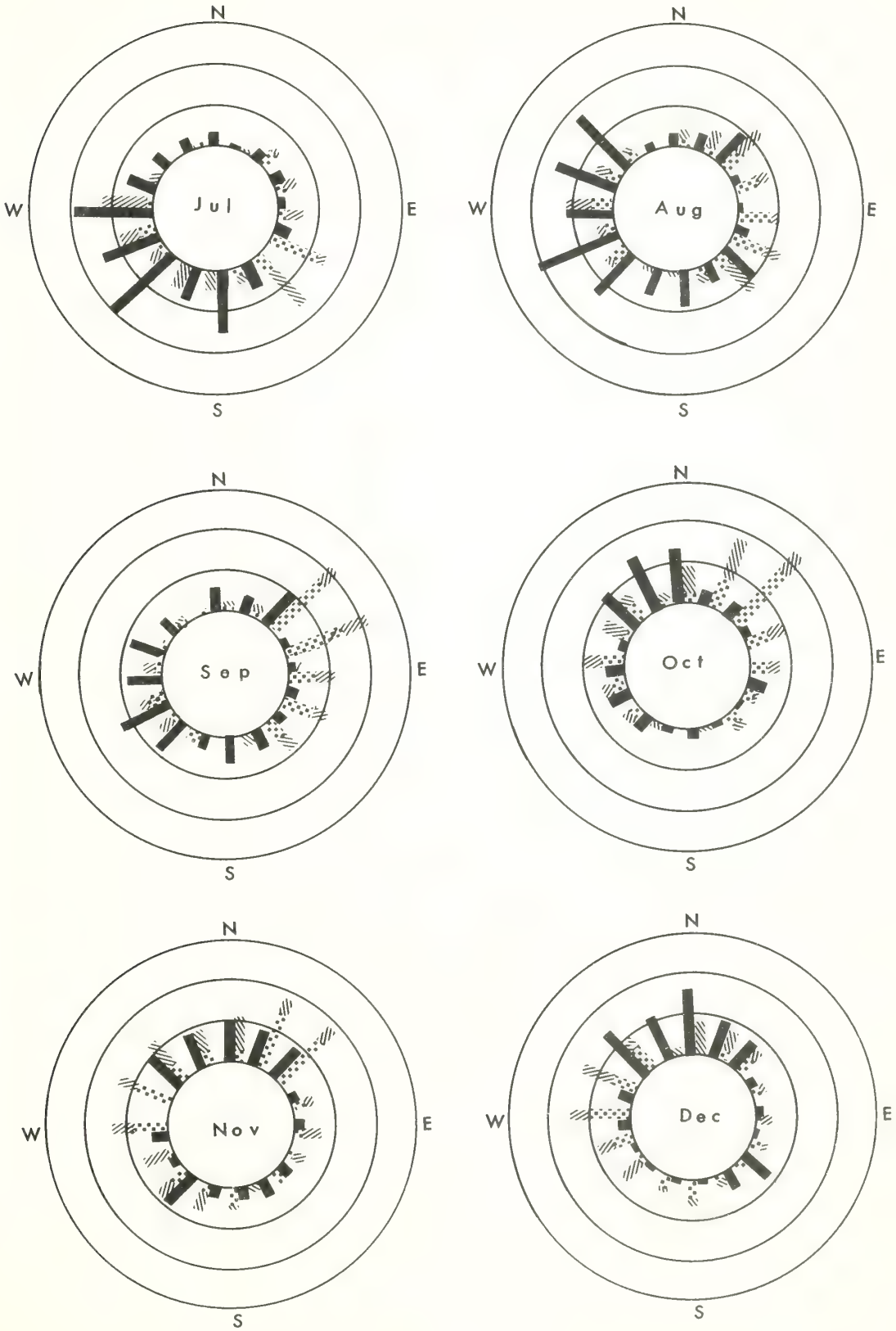




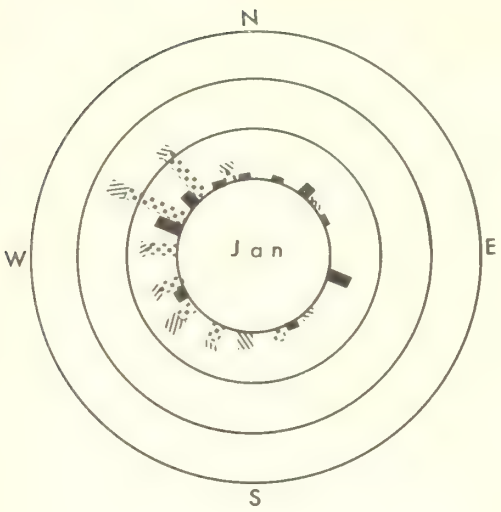


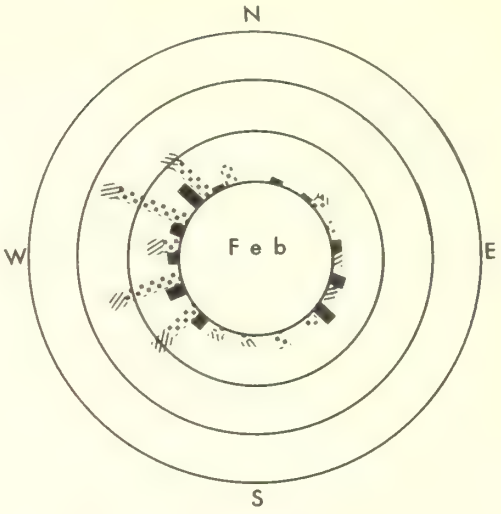


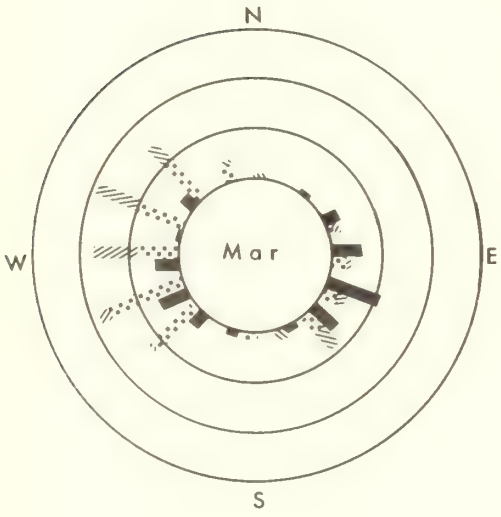
JACKSONVILLE, FLORIDA (daytime)

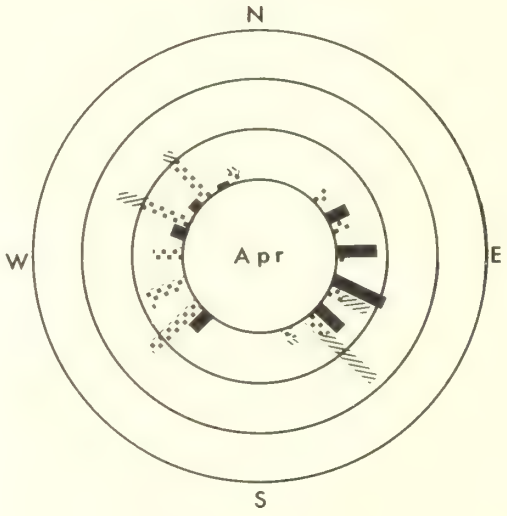


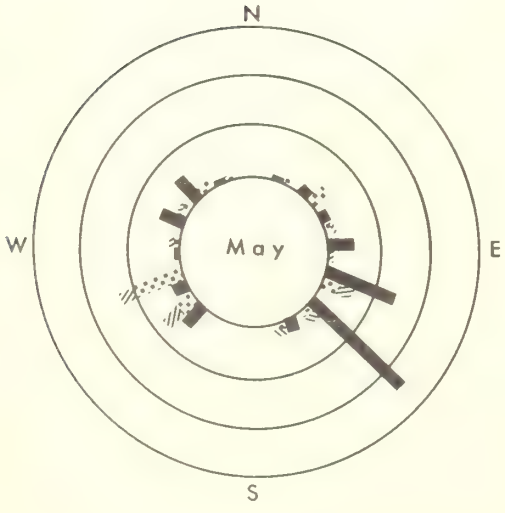
JACKSONVILLE, FLORIDA (nighttime)

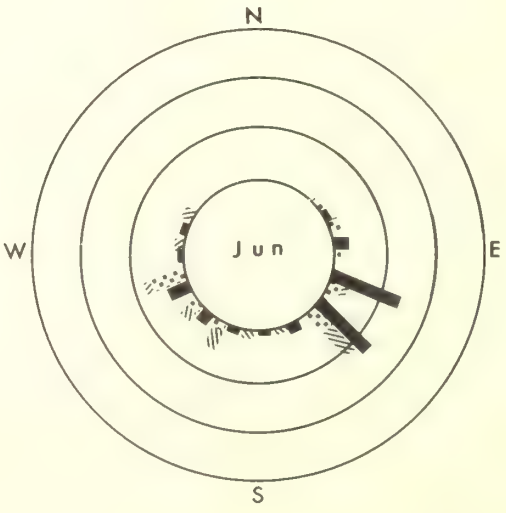




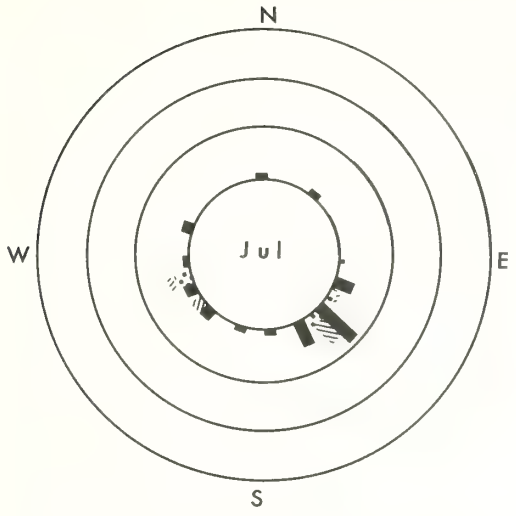


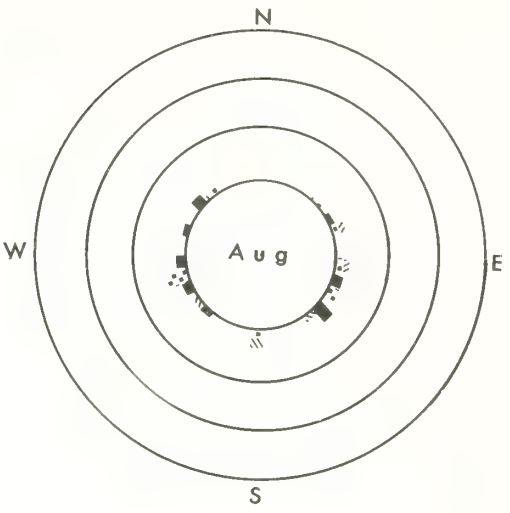


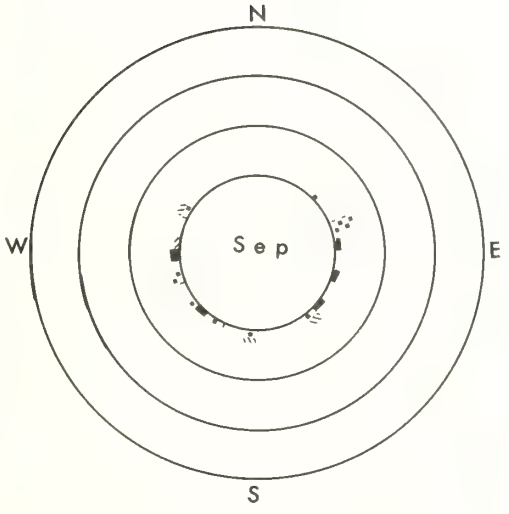


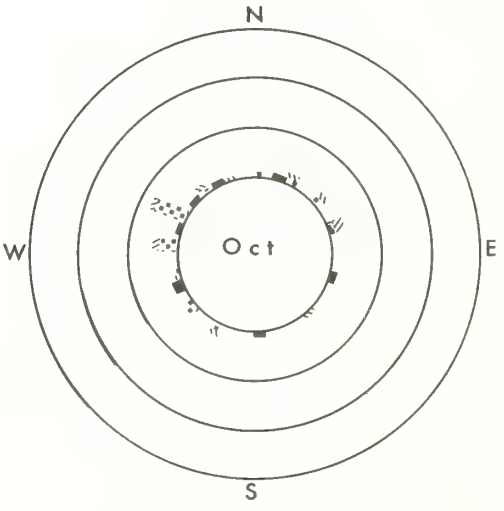


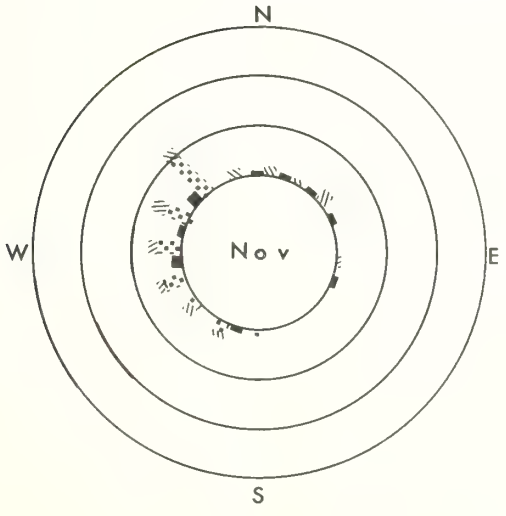
JACKSONVILLE, FLORIDA (nighttime)

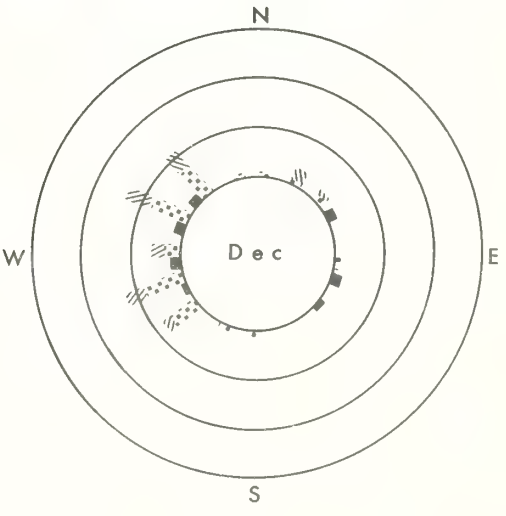




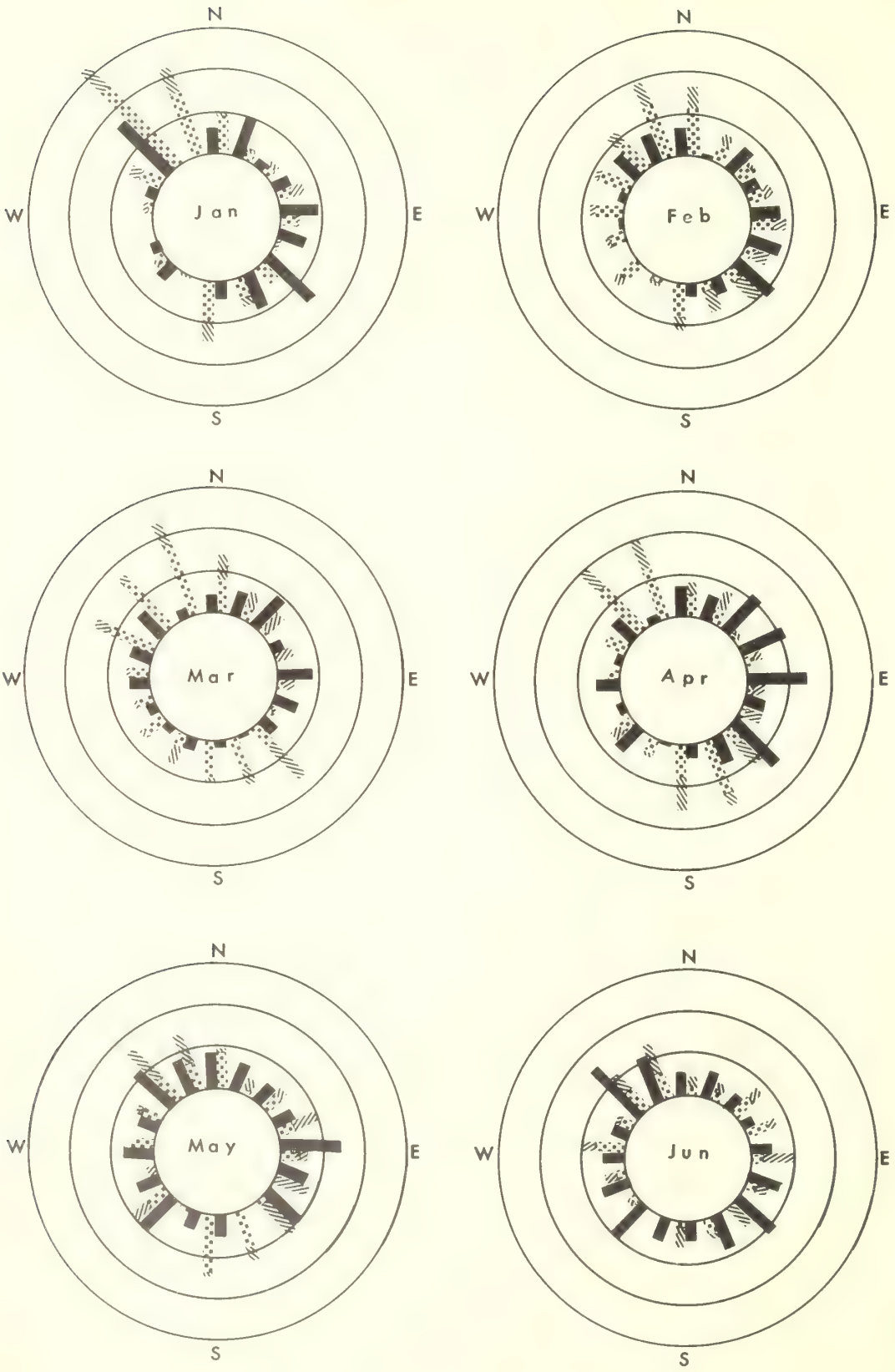




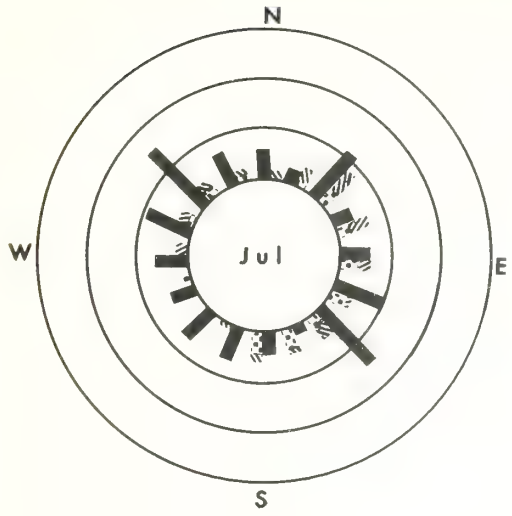


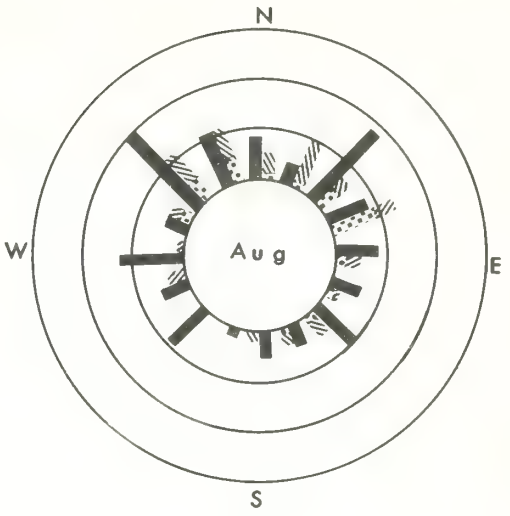


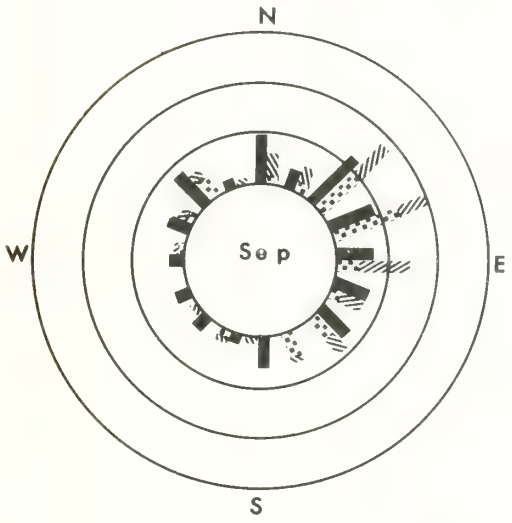
TALLAHASSEE, FLORIDA (daytime)

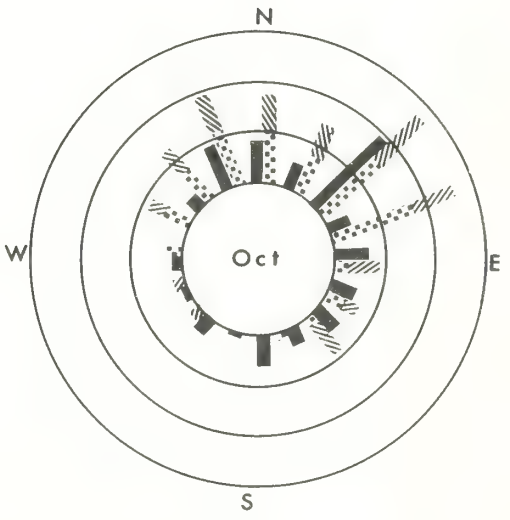


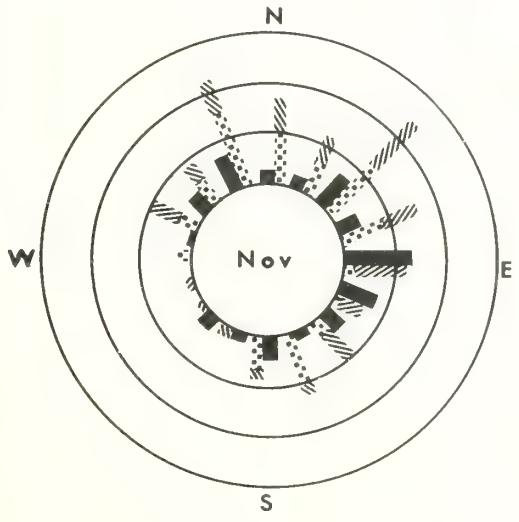
TALLAHASSEE, FLORIDA (daytime)

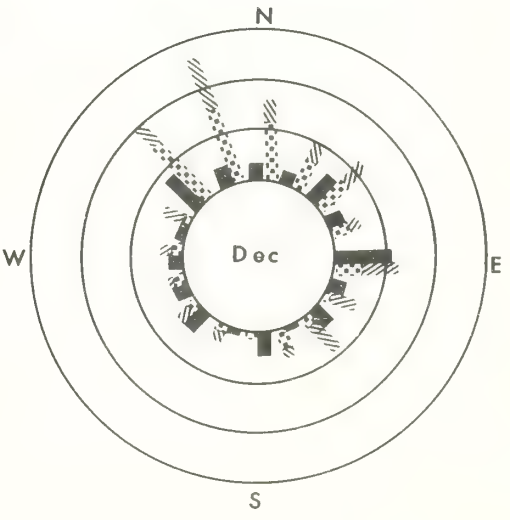




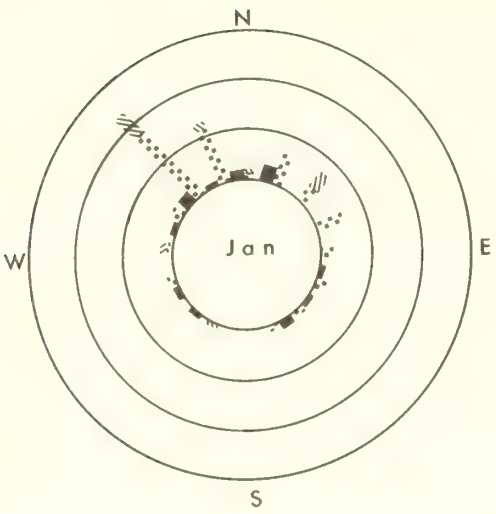


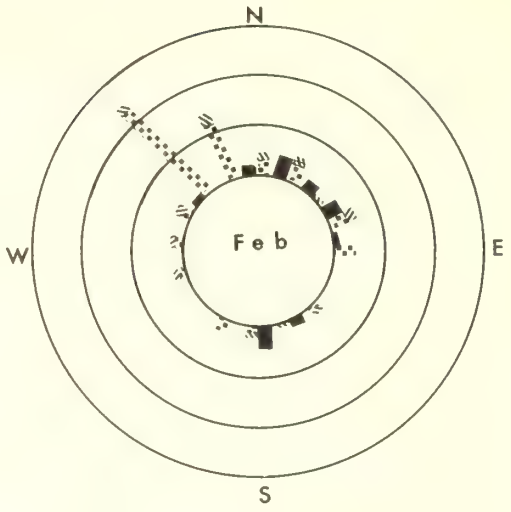


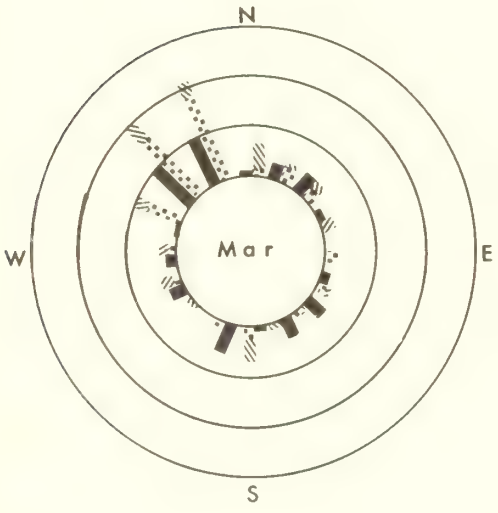


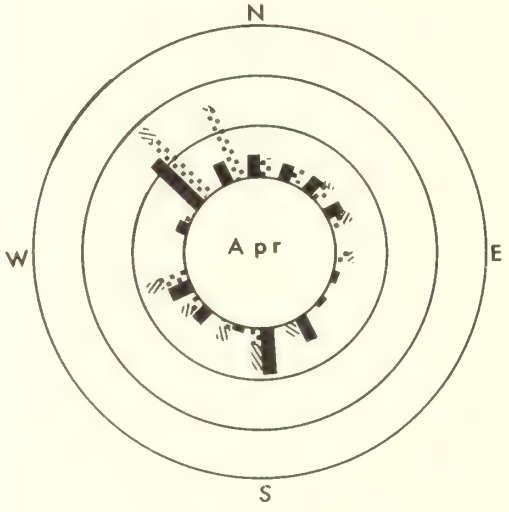


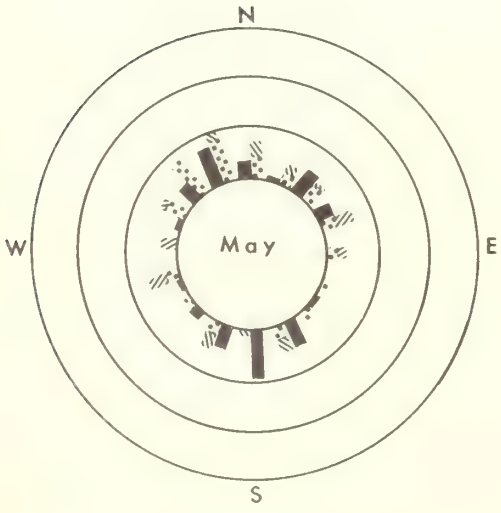
TALLAHASSEE, FLORIDA (nighttime)

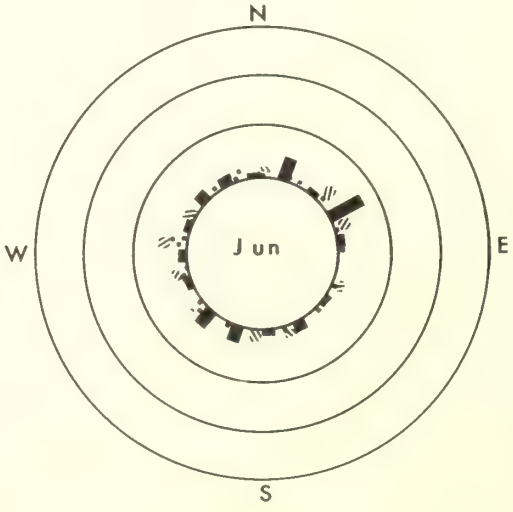




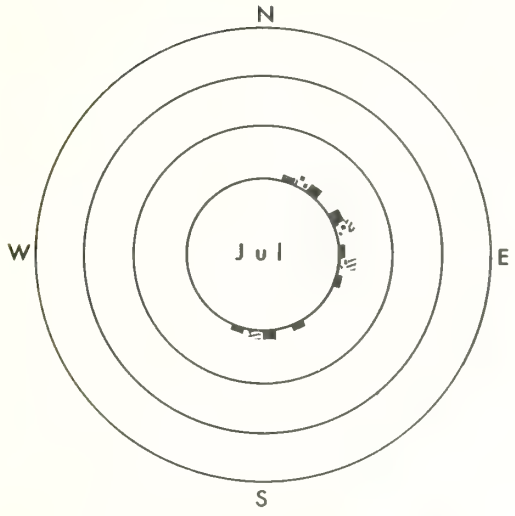


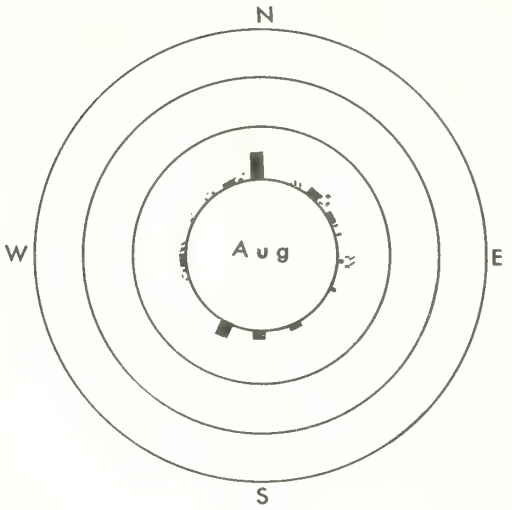


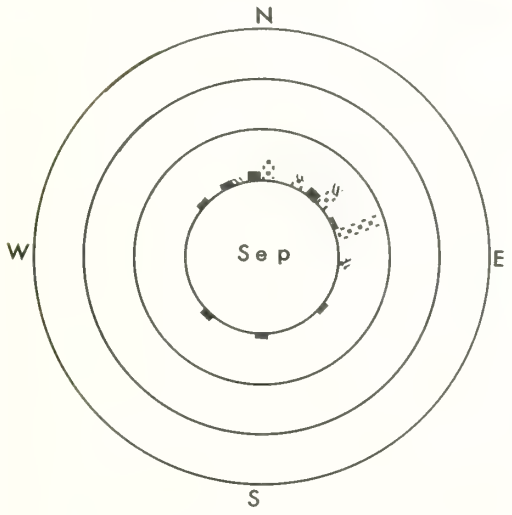


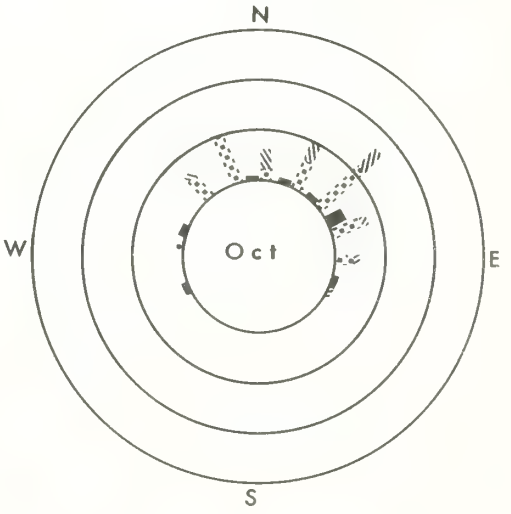


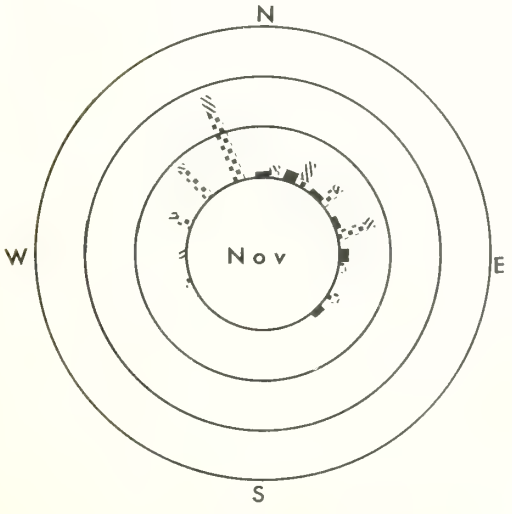
TALLAHASSEE, FLORIDA (nighttime)

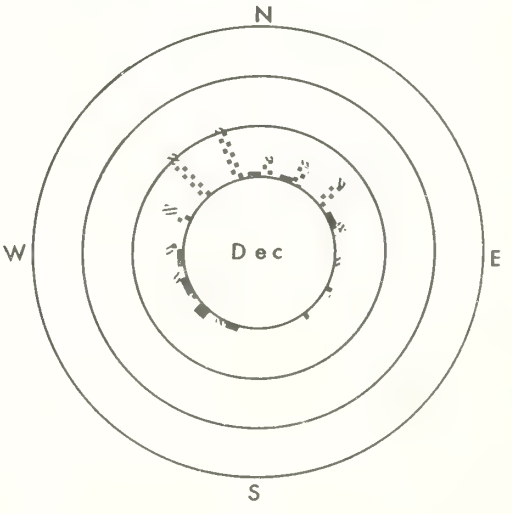




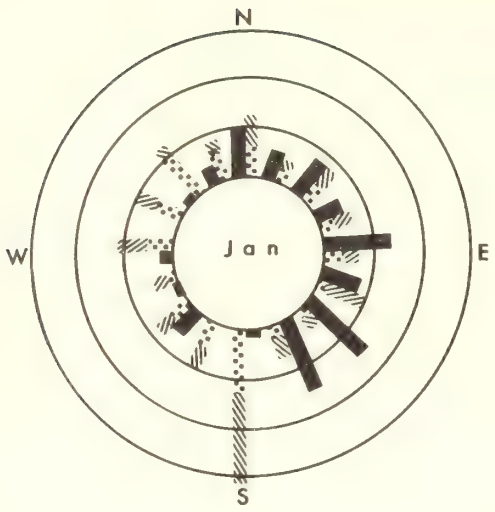


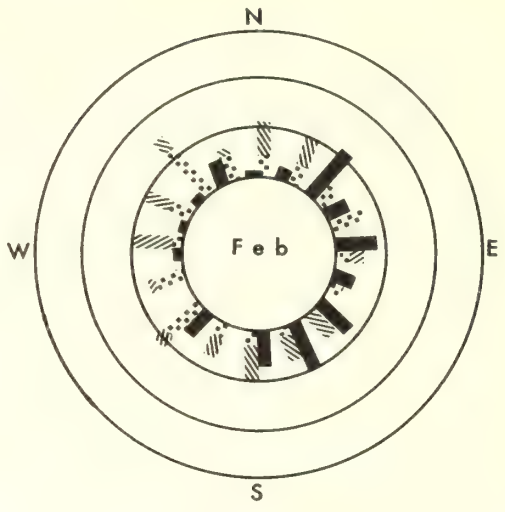


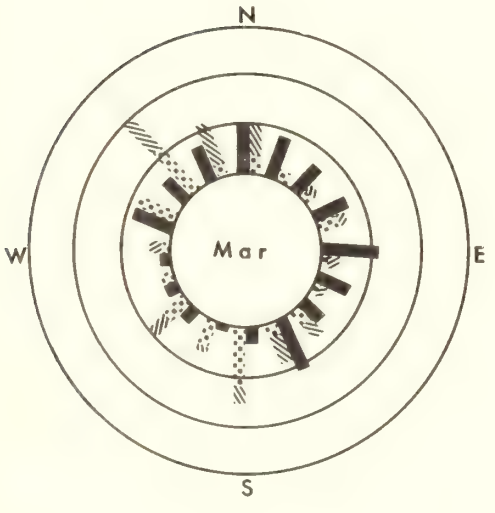


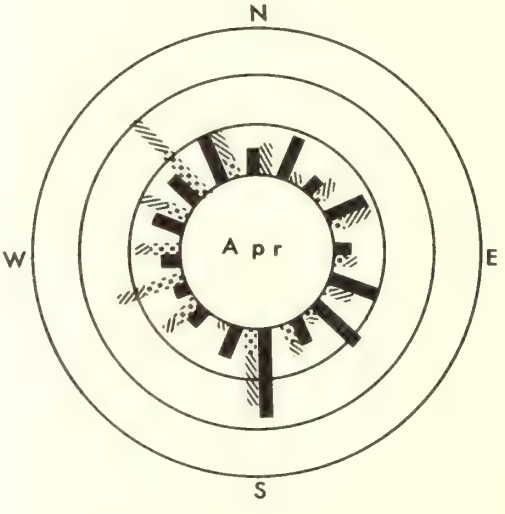


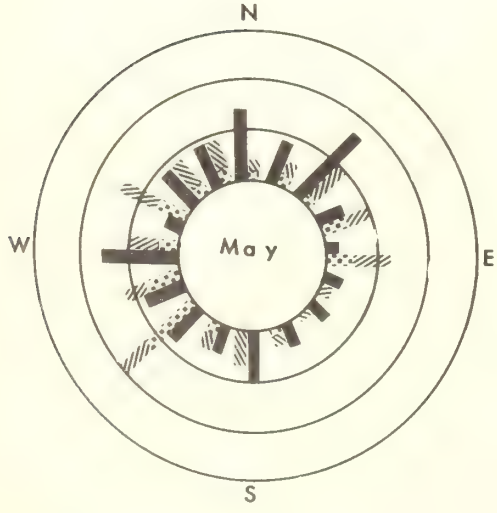
VALDOSTA, GEORGIA (daytime)

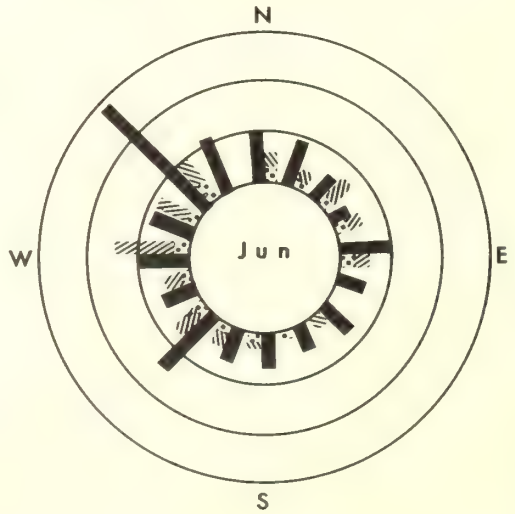












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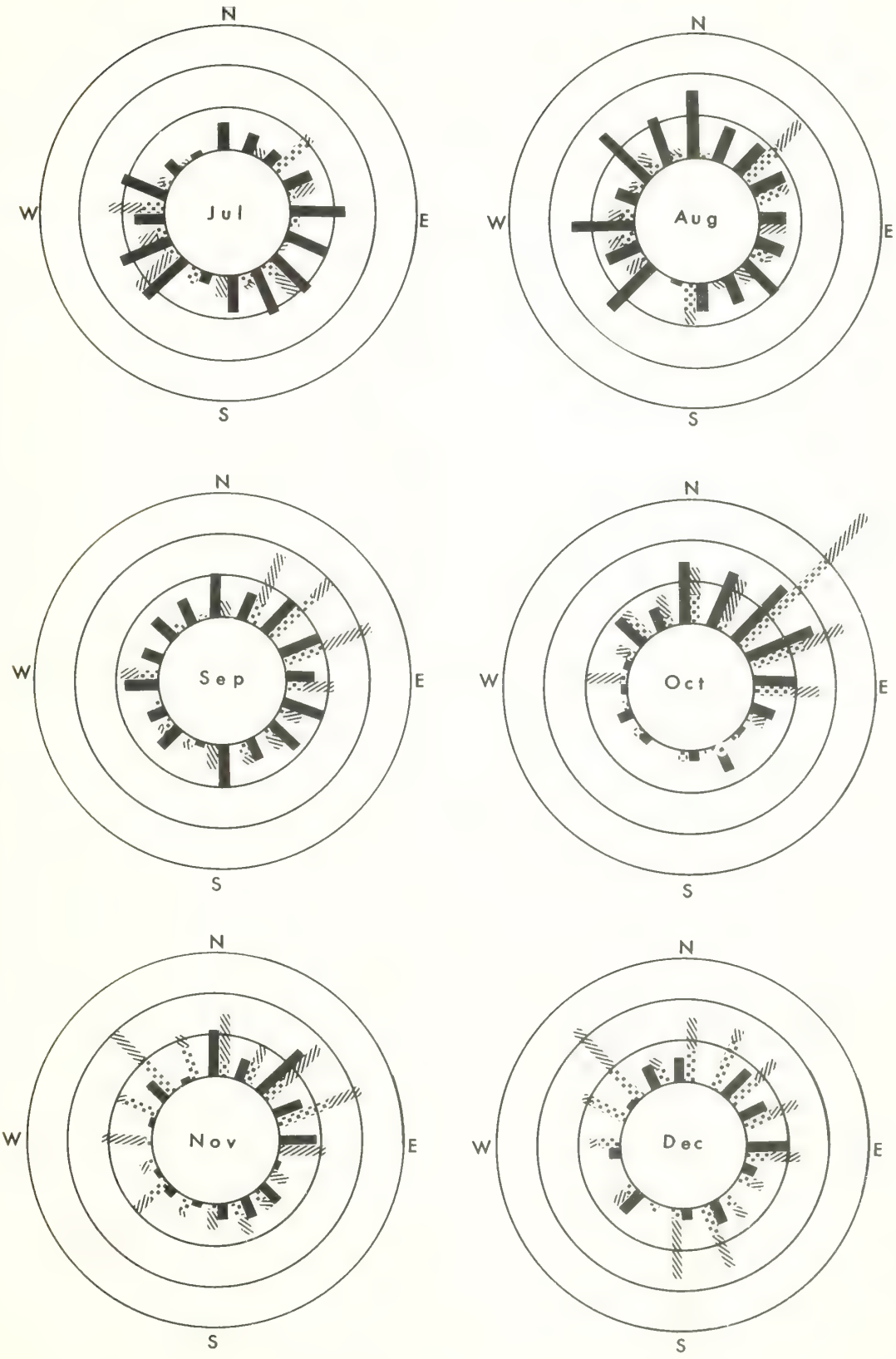

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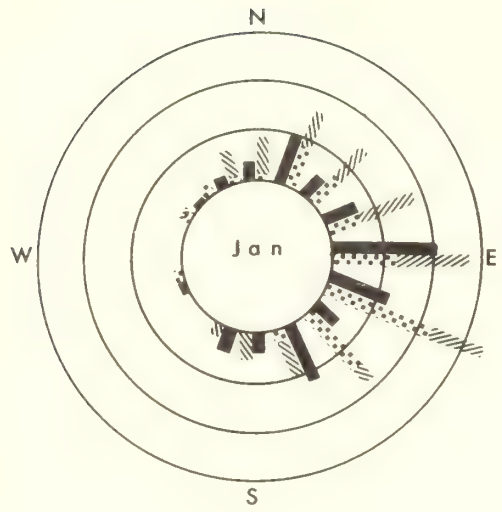

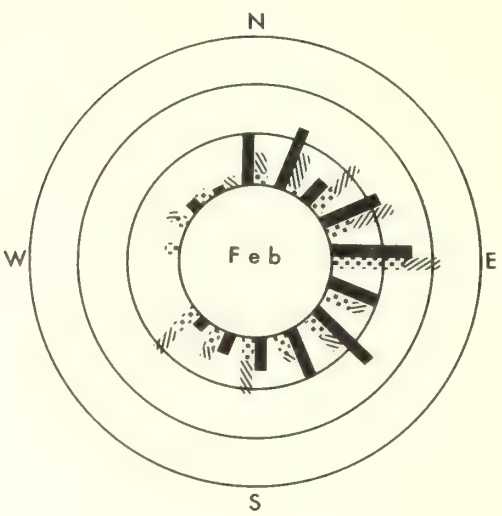

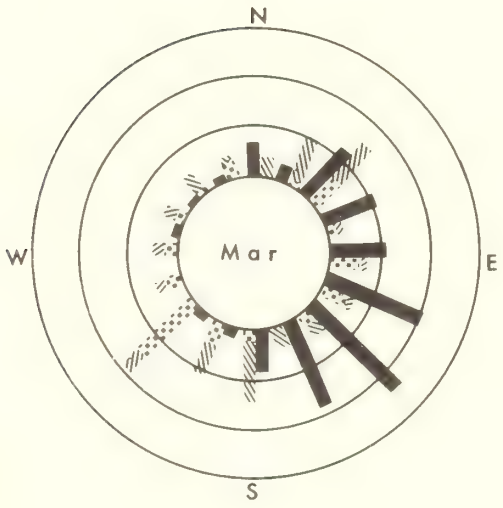

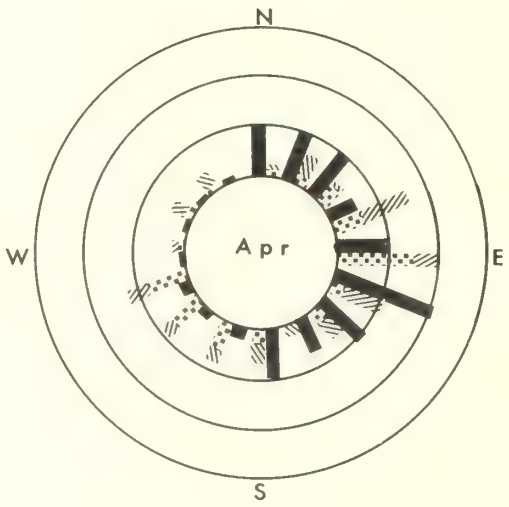

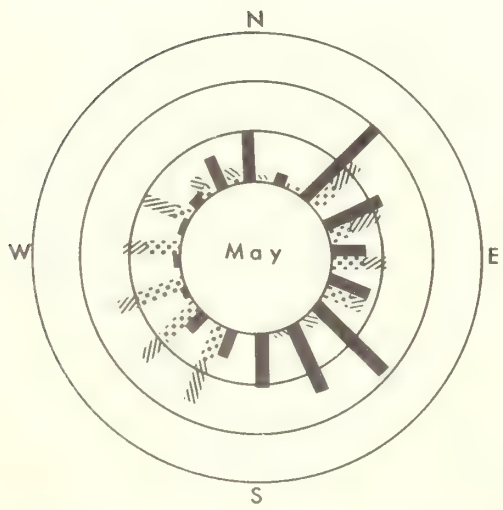

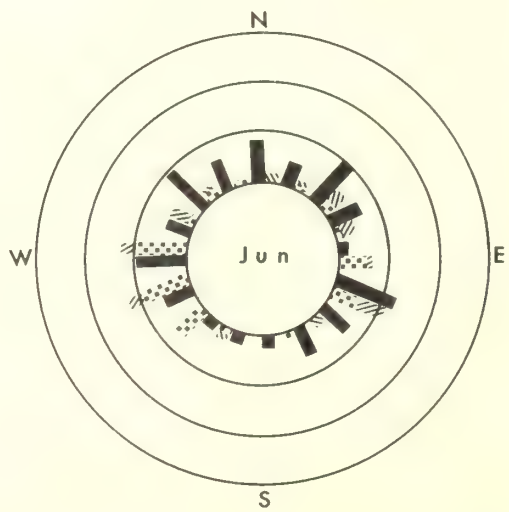

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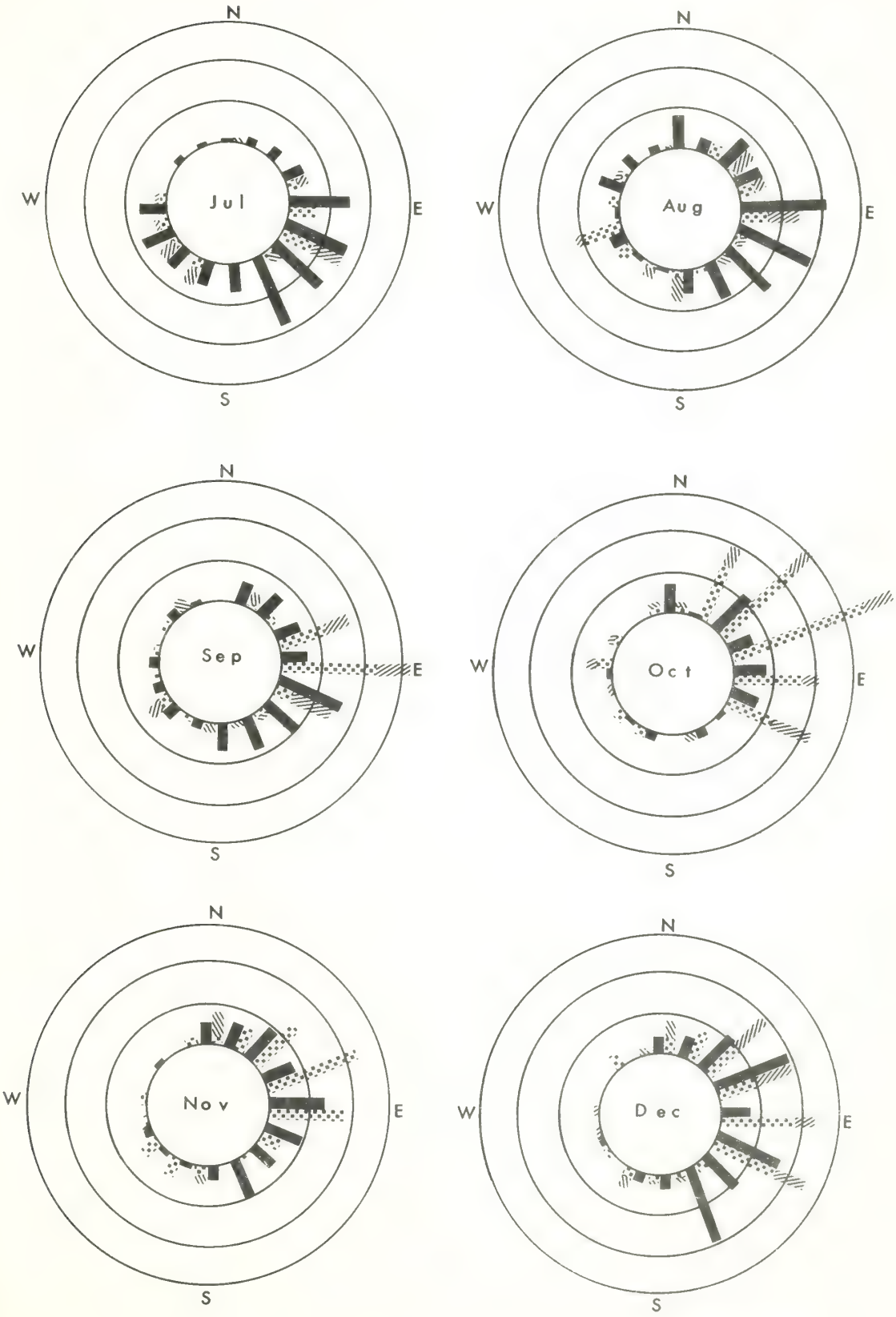

Agriculture · Asheville

station paper no. 132 october 1961

soil moisture as a source of base flow from steep mountain watersheds

by john d. hewlett

NOV 2 1961

Southeastern Forest Experiment Station
Asheville, North Carolina

U. Department of Agriculture - Forest Service

Soil Moisture as a Source of Base Flow From Steep Mountain Watersheds

by

John D. Hewlett

Coweeta Hydrologic Laboratory

INTRODUCTION

This paper reports initial trials of an artificial soil profile constructed on sloping ground to test the theory that long slow drainage of soil moisture sustains base flow in mountain streams. Work is continuing which is expected to prove or disprove these preliminary results.

On heavily forested slopes such as those at the Coweeta Hydrologic Laboratory in western North Carolina, nearly all water in flowing streams has passed in some fashion through the soil mantle. Despite progress in studies of the hydrology of small watersheds, there remains a gap in our practical knowledge of the behavior of water during this passage. At Coweeta the movement and storage of soil water is being studied to determine its contribution to streamflow. The experimental area is characterized by deep friable soils and an 80-inch average annual rainfall which produces little or no overland flow during storm periods. Perennial streams flow from steep mountain slopes even during rare summer droughts of 6 weeks or more in duration. The average annual yield of water is 37 area inches, of which roughly 85 percent is base flow.

GROUND WATER AS A SOURCE OF BASE FLOW

Although the nature of the yield has long been studied by hydrograph analysis and water balance techniques, the immediate source of this continuous supply of water is not well understood. It has been accepted by most hydrologists that sloping ground-water bodies feed the streams during nonstorm periods by hydraulic gradients between the stream channels and the outer extremities of saturated aquifers (Hoover and Hursh, 1943). Calculations based on ground-water depletion curves and fluctuations in a ground-water well led Hursh and Fletcher (1942) to conclude that a saturated aquifer at least 2 acres in extent was required to provide the observed flow from a 7-acre watershed at Coweeta. The hypothesized ground-water area was not actually traced out, but was accepted as a reality on the basis of several well records in the vicinity.

During Coweeta's early years, a total of 28 wells from 5 to 35 feet deep were installed at various locations, and fluctuations in water levels were recorded from month to month. Although the wells showed depletion and accretion as expected, it was discovered after many years that, when pumped dry, most of the wells failed to recover until heavy rains occurred. The wells were charged apparently by excess water from heavy rains, and subsequent leakage provided the appearance of depletion. Twenty-one wells were abandoned with the conclusion that they had been reflecting, not ground-water levels, but simply variations in "cistern" storage. The remaining seven wells were located near stream channels or in narrow mountain flood plains, where recovery after pumping may have been aided by subsurface stream water. Although no thorough ground-water survey has yet been made, experience with these wells suggests that ground-water bodies may be restricted to relatively narrow zones along the stream channels.

Thus, neglecting evidence based mostly on calculations, no extensive ground-water aquifer has been demonstrated at Coweeta. In fact, taking into consideration the steepness of stream profiles and the precipitous valley slopes, it is difficult to picture a ground-water aquifer of sufficient extent to supply streamflow through the growing season, when most current rainfall is

accounted for by expected rates of evapotranspiration. Indeed, to support the ground-water aquifer theory, on many of the watersheds, several covering a thousand-foot range in elevation, it would be necessary for ground water to exist for many weeks at hundreds of feet of hydraulic potential along stream channels which drop away at 45 percent slope.

Deep fissures in the underlying rock have been suggested as the location of extensive aquifers, although Coweeta watersheds apparently are underlain by watertight material. Fissures may supply some base flow. However, if a large percentage of flow came from this source, it would seem that the length of stream channels would shrink noticeably during the growing season and that many large springheads would be evident at lower elevations — a condition often characteristic of limestone areas. This does not seem to be the case at Coweeta, for the stream courses are remarkably stable and depletion tends to occur proportionally over the entire length during dry spells. Under present evidence, it seems unlikely that deep fissures are the origin of large percentages of base flow at Coweeta.

The soil mantle over much of the basin lies on slowly decomposing mica schists and gneisses. The depth of the weathered soil varies from 2 to more than 25 feet, and the mantle over many small watersheds averages about 6 feet in depth. After heavy rainfall, a 6-foot profile of medium-textured soil can hold briefly up to 30 area inches of water (42 percent by volume). Such storage potential, of which perhaps 8 inches (10 percent by volume) may be available for streamflow, dwarfs the apparent ground-water storage potential for these steep catchments. Where overland flow is negligible, nearly all evapotranspiration, ground water, and streamflow are derived from this huge temporary reservoir. If large ground-water areas cannot be demonstrated, it follows that unsaturated soil, or moisture in the field capacity range, must serve as the main storage aquifer and source of base flow on steep slopes. Almost imperceptible rates of drainage, operating over long periods of time on huge volumes of soil, may be sufficient in some cases to explain sustained base flow in mountain streams without recourse to the concept of extensive water tables or deep fissures in underlying rock.

REVIEW OF UNSATURATED FLOW IN FIELD SOILS

The literature on moisture movement in soil appears to be chiefly concerned with the application of Darcy's law, derived originally for flow in a saturated medium, to unsaturated flow. However, knowledge derived from these intensive studies has not been applied profitably to problems in hydrology. Concentration on agricultural drainage problems and the downward entry of irrigation water has tended to deflect attention from the mechanics of deep drainage subsequent to saturating rainfall. The subject is often closed with the statement that downward flow materially ceases after 2 or 3 days.

Nevertheless, the literature contains much indirect evidence to support the concept of unsaturated soil as a source of base flow in streams. Among the most pertinent early papers is one by Edlefsen and Bodman (1941), in which they described measurable drainage of a plot of soil after soaking by irrigation to a depth of 22 feet. With evaporation prevented by a multiple seal at the surface, they followed moisture changes in the top 9 feet over a period of 832 days. Drainage appeared continuous over the entire period (except for certain seasonal aberrations), and the average rate of downward movement between the 590th and 832nd day was calculated as 0.007 inch per day.

Ogata and Richards (1957) measured water content changes in the top foot of a sandy loam soil during a period of 50 days, and found downward flow after irrigation to be closely related to time by equations of the form

$$W = aT^{-b} \qquad (1)$$

where W represents moisture content in percent by volume, T is the time since beginning of drainage, and the values a and b are related to soil depth and physical properties. No time limit is indicated for the operation of this equation, suggesting an indefinite period of drainage. Robins, Pruitt, and Gardner (1954) measured a downward movement of 0.6 inch of water from the 0- to 3-foot layer during the 2nd to 8th day after irrigation. A simple calculation shows that this amount of moisture may eventually contribute 2000 cubic feet of water per acre to streamflow.

A recent paper by Nielsen, Kirkham, and van Wijk (1959) showed that drainage from a 5-foot profile of silt loam soil yielded from 0.5 to 1.2 inches of water between the 4th and 14th day after irrigation, or roughly 2000 to 3000 ft.^{3}/acre. Still more recently, Nixon and Lawless (1960) calculated from moisture measurements the movement of soil-water downward from a 20-foot profile of sandy soil. Approximately 11.2 inches of previously stored soil moisture passed downward during a 6-month dry season, from which they conclude that slow drainage from unsaturated soil may contribute significantly to ground-water recharge. These and other papers contain evidence that soil profiles exhibit gradients in moisture content for an indefinite period after the beginning of drainage, and indicate that, if the soil volume is large enough and no air-water interface impedes drainage, equilibrium in downward movement is attained only after a very long time.

Meinzer (1942) has called the region of the soil profile that is above the water table but below the effective rooting depth of vegetation, the "no man's land of hydrology." Remson, Randolph, and Barksdale (1960) concluded from their studies of this intermediate zone at Seabrook, New Jersey, that downward gradients of hydraulic head produce slow but continuous rates of drainage even during the season of evapotranspiration.

To this author's knowledge, no effort has been made to apply the increasing information in this field to the general problem of water storage and yield on steep slopes. The following experiment was designed to test the existence of soil moisture gradients in sloping profiles and to point out their importance in small watershed hydrology.

METHODS OF STUDY

Consideration of the difficulties in separating soil texture and depth effects from topographic and gravitational influences on natural slopes led to the adoption of a soil model for an initial study of the storage and movement of moisture on slopes. Techniques were developed as the experiment progressed; the first two phases of the study are reported here.

Phase I. The model used in Phase I was constructed of wood and concrete on a 40 percent slope under a forest canopy; pertinent details are diagrammed in figure 1. The artificial profile was 18 inches deep, measured perpendicular to the slope, 24 inches wide, and 24 feet long. The sandy loam soil excavated from the subsoil of a natural profile was mixed and carefully tamped into the structure to reproduce as closely as possible its original bulk density. Although quite free of stones, the soil was screened through a quarter-inch mesh to remove large aggregates which may have contained concentrations of colloidal material. Physical characteristics, as sampled from the model, are listed in table 1. The soil was analyzed by pressure plate (Richards and Weaver,

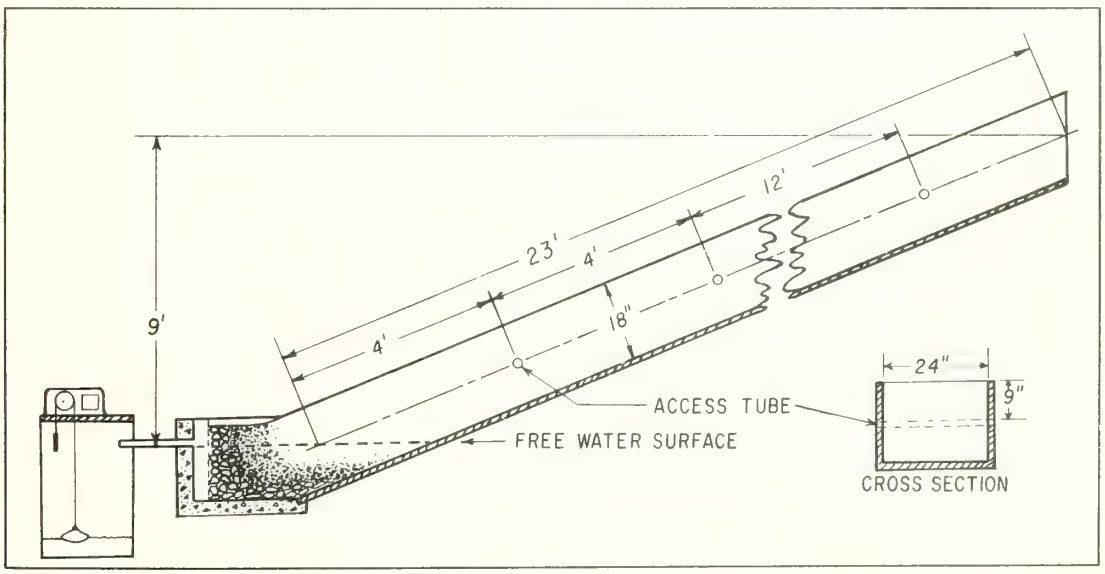

Figure 1. --Schematic diagram of the soil model as used in Phase I. The axis of the model rises at a 40-percent slope.

Table 1.—Physical characteristics of the soil used in the model, Phase I

Soil characteristic	Mean	Std. Dev.
Bulk density in original position	1.33	0.06
Bulk density when packed in model	1.35	.07
Percent moisture by weight when packed	18.0	1.0
Percent moisture by volume when packed	23.0	2.1
Percent moisture by volume at saturation	49.0	1.5
Percent moisture by volume under 40 cm. tension	36.0	1.3
Percent moisture by volume under 60 cm. tension	32.0	1.6
Percent sand*	60	—
Percent silt*	18	—
Percent clay*	22	—

*Measured by the Bouyoucos method of hydrometer analysis.

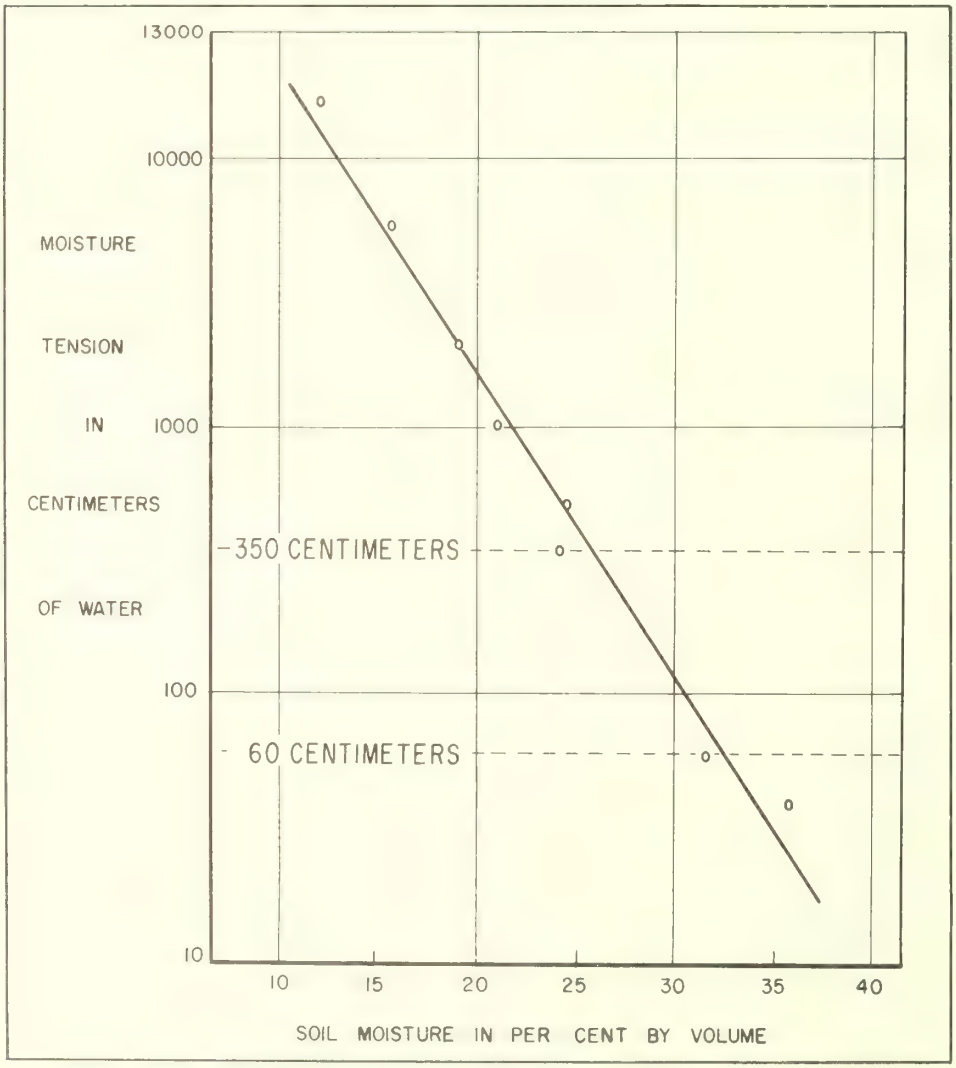

Figure 2. --Graph showing the relationship between soil moisture tension and soil moisture content. Each plotted point represents five or more samples of the experimental soil.

1943) and by tension table methods (Hoover, Olson, and Metz, 1954) to determine moisture retention characteristics from 40 to 15,000 cm. of water tension. Figure 2 shows a linear relationship over the specified range between moisture content and the logarithm of moisture tension.

A free water surface, or "water table," was maintained at a fixed level within the soil by an outlet pipe at the base (fig. 1). The difference in elevation between the "water table" and the top of the model was 9 feet. Special care was used in constructing the soil-water interface at the base of the sloping column. Downward-moving water passed from saturated soil (below the free water surface) into a sand-soil mixture, into coarser sand, fine gravel, and finally into larger spaces between 2-inch stone. In this manner, it was assumed that a gravelly stream bed was fairly well simulated.

The inside surfaces of the structure were lined with roofing paper, painted with tar, and sprinkled with sand to provide a good frictional surface. The surface inch of the soil column was mixed with ½ inch of organic litter and covered with a layer of cheesecloth to prevent puddling and erosion of the soil under sprinkling. After sprinkling, evaporation was practically eliminated by placing a double layer of polyethylene plastic over the surface.

Access tubes for the measurement of soil moisture by the neutron-scattering method were installed at 4, 8, 12, 16, and 20 feet (slope distance) from the water table (fig. 1). These were oriented horizontally to avoid the possibility of vertical movement of soil water along the tubes. The meter used was Nuclear-Chicago's Model 2800 scaler and P 19 probe, which provided estimates of moisture with a standard error of the order of 0.3 percent by volume. Readings were taken from the center of the column of soil, allowing ample margin to include the "sphere of influence" of the radioactive source at the moisture contents investigated. Repeated readings in the access tubes provided an exceptionally high degree of precision in estimating moisture changes with time.

Operating procedure was to soak the entire column by application of spray to the sloping surface. This was done repeatedly over a period of 48 hours to insure positive drainage and complete soaking. The ground water remained clear throughout this treatment. Moisture contents were measured at the five access tubes until it was determined that the entire column of tamped soil would not take more than 41 percent by volume (about 7 percent short of saturation) without exceeding the percolation capacity and causing surface runoff. The aim was not to simulate actual rain but rather a soil profile fully charged under sustained rainfall.

Within a few minutes after the last application of water, moisture was read at each access tube to establish beginning storage patterns. Repeated readings at the same points allowed moisture changes to be followed over the next 10 days.

The base of the model developed a leak during the soaking period, making it impossible, as was originally intended, to follow outflow accurately by a water-level recorder. However, it was observed that outflow continued throughout the 10 days and was still dripping from the bottom of the model when this phase of the experiment was terminated. Finally, comparison was made between soil moisture content and moisture under 60-cm. tension as determined in the laboratory on 18 undisturbed samples collected from three depths at six intervals up the slope of the model.

Phase II. In a renewed effort to obtain long-term records of outflow from the model, the water-table section was rebuilt by extending the concrete portion at the base, thus enclosing the entire water-table zone in concrete, and incidentally lengthening the model from 24 to 32 feet (fig. 3). Soil from the same source was repacked in the model, but a lower bulk density (average 1.24) resulted owing to inadequate tamping. A recording soil thermometer was located in the center of the column of soil, halfway up the slope. The soil was soaked and the entire procedure of Phase I was repeated, except that soil moisture and outflow were measured for 71 days, from August 11 until October 19. An FW 1 Friez water-level recorder gave a continuous record of water flowing out of the soil.

RESULTS

Phase I. During the soaking operation, small leaks developed along the column, particularly around the neutron probe access tubes, indicating positive hydraulic pressures within the soil. Within a short time after soaking, the leaks stopped, suggesting the development of negative pressures as tension was established on the column. Small holes bored in the soil at the base of the model revealed only temporary changes in the free water level during soaking. As far as could be determined, the water level remained constant during succeeding days of drainage.

The pattern of drainage from the 72 ft.^{3} of soil over 10 days is illustrated in figure 4. The moisture content at the beginning averaged 40.5 ± 1

Figure 3. --Reconstructed soil model (Phase II) in operation, showing some of the instrumentation used. Upper left, recording soil thermometer; lower left, water level recorder; right, neutron-scattering device for measurement of soil moisture.

percent by volume. Reductions in moisture content were at first rapid, but most rapid at the upper levels. A moisture gradient had developed after 15 hours, with 8 percent more moisture at the 4-foot slope distance than at the 20-foot distance. When the rate of loss from the top began to level off, the two lower positions increased their net rate of loss, reflecting the reduced supply from up-slope. After 48 hours, relative drainage continued fairly constant at all points, but a definite gradient remained up-slope. The pattern indicates that up-slope moisture is continually recharging down-slope storage, which in turn feeds the ground-water table.

A comparison between the 60-cm. tension moisture content and final moisture contents along the column is shown graphically in figure 5. Results are separated into three 6-inch depths at six equidistant stations along the column. Each plotted point represents the percentage of field moisture as a deficit or surplus over the 60-cm. tension value, determined after saturating the sample according to methods described by Hoover, Olson, and Metz (1954). Positive values indicate that the sample in the soil column contained water in excess of 60 cm. of tension, whereas negative values indicate qualitatively the degree of moisture deficit below this tension level. These curves illustrate the existence of different conditions of moisture stress along the slope, as well as with depth below the surface.

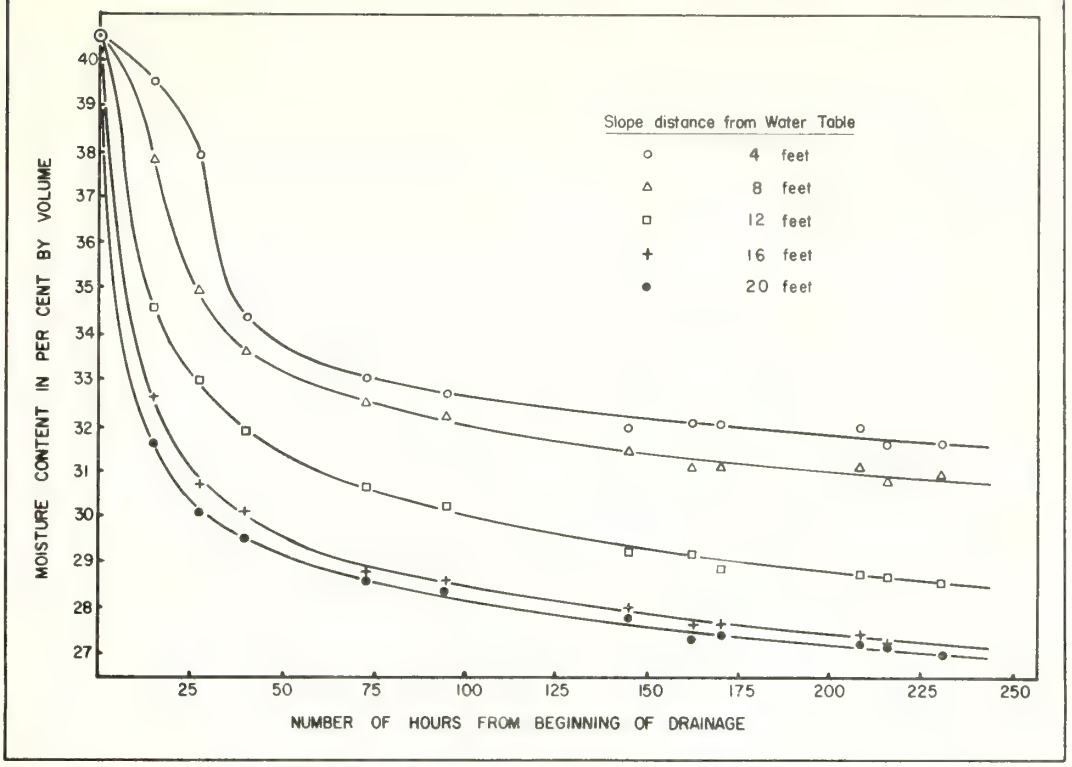

Figure 4. --Soil moisture content at various slope distances from the water table plotted against time since the beginning of drainage, Phase I.

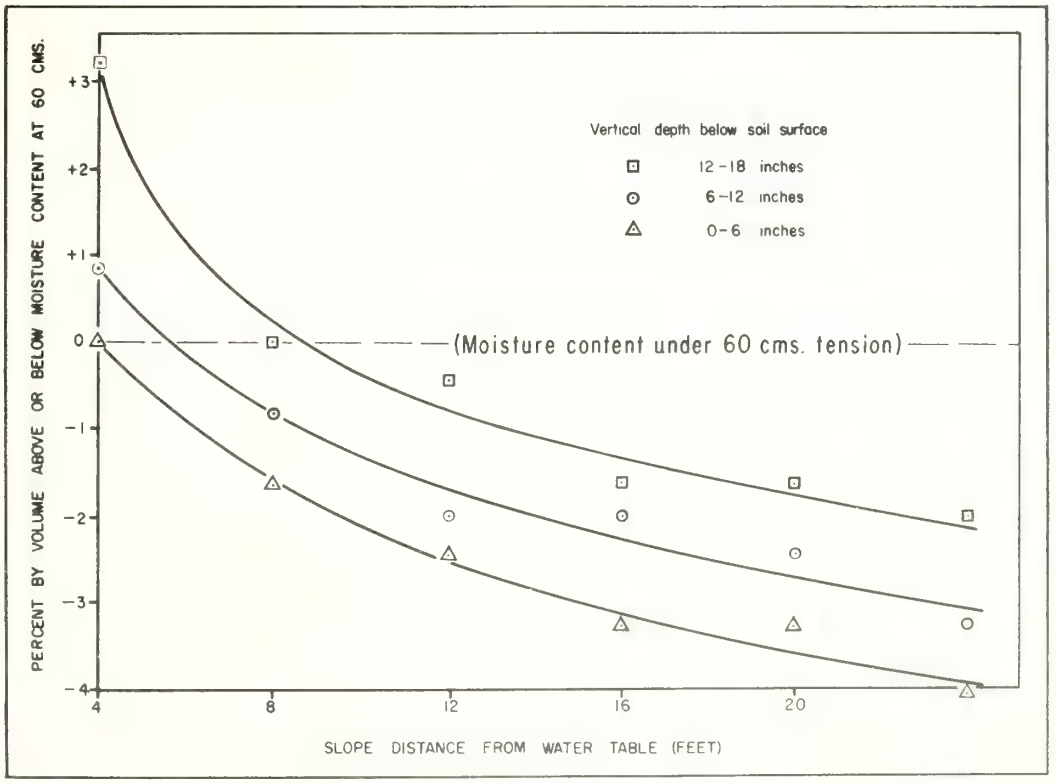
PERCENT BY VOLUME ABOVE OR BELOW MOISTURE CONTENT AT 60 CMS.
SLOPE DISTANCE FROM WATER TABLE (FEET)
Vertical depth below soil surface
12-18 inches
6-12 inches
0-6 inches
(Moisture content under 60 cms. tension)

Figure 5. --Comparison between the final moisture content of 18 undisturbed samples from the soil model and their moisture content after equilibration under 60 centimeters of tension, Phase I.

Phase II. The repacked and lengthened model was charged on August 11 and ceased to yield water to the measuring device on October 21. A total of 13.2 ft.^{3} of water drained from 84 ft.^{3} of soil during 71 days, of which 2.6 ft.^{3}, or 20 percent, came after 3 days. Only 0.6 cubic foot of water drained during the last 50 days, but, if multiplied by appropriate factors, this discharge is equivalent to about 0.3 ft.^{3}/sec./mi.^{2}. Such a rate is of the order of magnitude of observed minimum flows from Coweeta watersheds.

Soil moisture contents and tension gradients in the second phase were similar to those in the first phase. However, early discharge of the repacked model was more rapid, the total yield per cubic foot of soaked soil was greater, and the final soil moisture tension gradient was less pronounced than in the first run. Presumably the lower bulk density, and consequently the increased total pore space within the soil, favored more rapid internal drainage as well as reduced moisture gradients up the slope.

Discharge was intermittent after the 30th day, causing some difficulty in securing average rates of outflow during the last half of the drainage period. The average hourly yield from the 1st to the 30th day is plotted in figure 6, showing an approximately linear relationship between the respective logarithms of outflow and elapsed time. These rates of flow are analogous to changes in soil moisture after irrigation found by Ogata and Richards (1957), Nixon and Lawless (1960), and others. Rate of discharge is equivalent to the change in moisture content of the entire column of soil with respect to time (dW/dT), which may be obtained by differentiation of equation 1

$$dW/dT = -abT^{-b-1} \qquad (2)$$

Calculating from the observed rates of drainage plotted in figure 6, equation 2 becomes approximately

$$dW/dT = -0.92T^{-1.68} \qquad (3)$$

where dW/dT is in ft.^{3}/hr. and T is in days from beginning of drainage.

DISCUSSION AND CONCLUSIONS

It is recognized that not only are actual conditions on watersheds physically different from the artificial soil profile used here but they are subject to additional influences — particularly evapotranspiration. Field demonstration of a persistent tension gradient adjacent to streams is still necessary. However, present results suggest that an analysis of water yield based on negative hydraulic gradients in unsaturated soil may provide a better working hypothesis for studying base flow as well as other hydrograph characteristics in the mountains than the traditional ground-water concept.

From the standpoint of the hydrologist, one of the most fundamental expressions of the relationship of soil to water is contained in the curve which relates moisture content to soil moisture tension. Figure 2 shows the moisture retention of the experimental soil to be linear with the logarithm of tension, at least over the 40- to 15,000-cm. range. Field capacity, always a rather arbitrary value, is reported by various investigators to be from 60 to 350 cm. of moisture tension. It can be seen from the curve that roughly 7 percent moisture by volume (0.84 inch of water per foot of soil depth) is contained within the range of field capacity, to be yielded slowly as tension increases in the soil profile. Thus the persistence of negative hydraulic gradients and their gradual approach to equilibrium can result in a steady accretion to ground water and streamflow from unsaturated soil. Furthermore, there is some evidence from this study that slow drainage will result in gradients in soil moisture stress on natural slopes. Allowing a short period of adjustment following rainfall, a gradual decrease in moisture content with increasing elevation above the stream channel may be expected, and is usually observed on steep slopes. Changes in growth form and a tendency toward xerophytism in vegetation on ridges, even where soil depth is adequate and rainfall superabundant, may be related in part to this gravitational readjustment of soil moisture in mountainous areas.

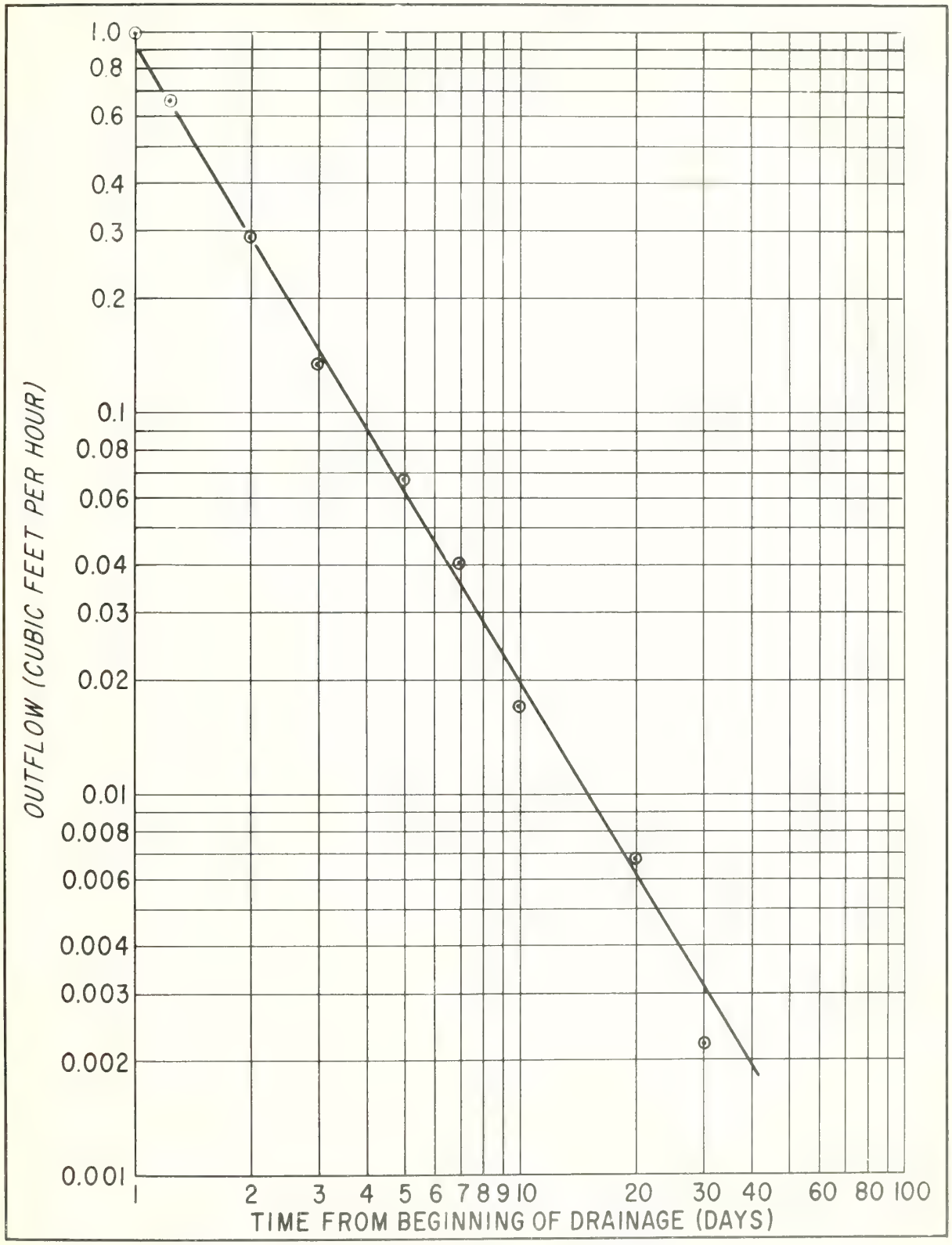

Figure 6. --The relationship between outflow (dW/dT) from the entire soil model, Phase II, to time from beginning of drainage.

Using the artificial soil profile described here, it was found that both changes in moisture content at each level and total outflow agreed closely with the expression developed by Ogata and Richards (1957):

$$W = aT^{-b}$$

Differentiation of this equation gives a similar expression for the rate of drainage. If unsaturated aquifers of small watersheds can be characterized by soil type, size, and elevation above the stream channel, their basic contribution to streamflow under a given rainfall regime might be calculated through a series of such expressions. The integration of rates of unsaturated flow from a watershed will prove to be complex indeed, but the customary explanation of base flow solely in terms of ground-water recession may conceal some of the chief characteristics of stream behavior in steep terrain.

A practical implication of the concept of soil moisture as a source of streamflow concerns the hydrology of headwater regions. Referring to the model, if rain occurs uniformly over the surface of the column after drainage has diminished from a previous soaking, the deficit at the bottom will be quickly satisfied and stormflow will occur. A longer period of time will be required to satisfy deficits farther up-slope, but if rainfall continues, gradual soaking will increase the area contributing to stormflow at the bottom. The tendency, however, should be for up-slope rain to charge the soil mantle in preparation for succeeding days and weeks of base flow, whereas down-slope rain and channel interception will furnish most of the stormflow. The effects of such a system on watershed treatments to stabilize streamflow or increase water yield from steep watersheds may be considerable. For example, recognition that areas immediately adjacent to small streams provide a disproportionate percentage of stormflow may bring about an even greater concern than now exists for the protection of stream environs.

This preliminary study suggests that soil moisture gradients on slopes are partly due to unsaturated flow in response to hydraulic gradients within the soil mass and that these gradients may be sufficient in magnitude to demand consideration in hydrograph analysis, as well as in planning watershed treatments to stabilize or increase water yield. In addition, it seems quite likely that the major source of sustained base flow in Coweeta streams is soil moisture, although some storage undoubtedly exists in saturated ground-water aquifers. A larger experimental soil model is planned, to be equipped with a deeper artificial profile and improved instrumentation, to determine the validity of these initial results.

SUMMARY

At the Coweeta Hydrologic Laboratory the concept of saturated ground-water aquifers does not seem adequate to explain base flow. It is suggested that soil moisture in the range of field capacity is the source of a large percentage of base flow and that moisture is fed down the slope under negative hydraulic gradients.

A 1.5 x 2 x 24-foot soil model was constructed on a 40 percent slope, with an artificial water table at the base. After the soil had been soaked and the surface covered to prevent evaporation, drainage was followed during the next 10 days by neutron-scattering methods for measuring soil moisture. Outflow decreased with time, and the pattern of drainage indicated that it was taking place under tension rather than under positive hydraulic gradients. Actual moisture contents on the tenth day, as determined on undisturbed samples, demonstrated gradients in soil moisture tension both vertically and throughout the 24-foot slope. Moisture contents followed the same trend, showing that at partial equilibrium more water was retained down-slope than up-slope. Measured drainage from a lengthened and repacked model, also covered to prevent evaporation, continued for 71 days, during which the logarithm of the outflow rate was linearly related to the logarithm of time since beginning of drainage.

The mechanism of flow production is discussed, as well as some hydrologic implications of unsaturated flow in sloping soil profiles.

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Agriculture - Asheville

Station Paper No. 133 November 1961

Some Effects of Prescribed Burning on Coastal Plain Forest Soil

by

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SOME EFFECTS OF PRESCRIBED BURNING ON COASTAL PLAIN FOREST SOIL

by

Louis J. Metz, Thomas Lotti, and Ralph A. Klawitter

The usefulness of prescribed burning in the Southeast is well documented (Chaiken, 1949; Lotti and McCulley, 1951; Lotti, 1956; Wenger and Trousdell, 1957). It has been used with advantage for hazard reduction, for seedbed preparation, and for the control of broadleaved species where pine is to be the principal crop. However, the subject of prescribed burning often raises the question, "What effect does it have on the soil?" This is a pertinent question in view of the wider application of the technique with each passing year.

In an attempt to measure the effect of prescribed fire on the vegetation and soil, a study was installed in 1946 by the Southeastern Forest Experiment Station on the Santee Experimental Forest of the U. S. Forest Service, and the Westvaco Experimental Forest of the West Virginia Pulp and Paper Company. Both areas, located north of Charleston, South Carolina, are in the lower coastal plain, with loblolly pine (*Pinus taeda* L.) the predominant tree species. This report concerns the soils aspect of the study. Lotti *et al.* (1960) have already described the effects on vegetation, concluding that adequate understory control or seedbed preparation is obtainable with no serious damage to the pine growing stock.

REVIEW OF LITERATURE

Most of the work in the South on the effect of fire on soil properties has been done in the longleaf pine (*Pinus palustris* Mill.) type during the 1930's. The majority of the studies concerns wildfires rather than prescribed burning. Heyward made the most thorough investigation and reported, along with others, on several aspects of the problem.

Heyward and Barnette (1934), working in coastal plain longleaf pine stands from Virginia to Louisiana, found that the pH was higher on burned soil because of release of mineral elements in the ash. The calcium content increased 100 percent and the nitrogen 14 percent on the burned soils. All observed chemical changes ascribable to fire were restricted to the top 4 to 6 inches of soil. Concerning the physical state of the soil, the authors wrote: "The mellow, permeable surface soil on unburned areas contrasted strikingly with the compact, impermeable soil on the burned areas."

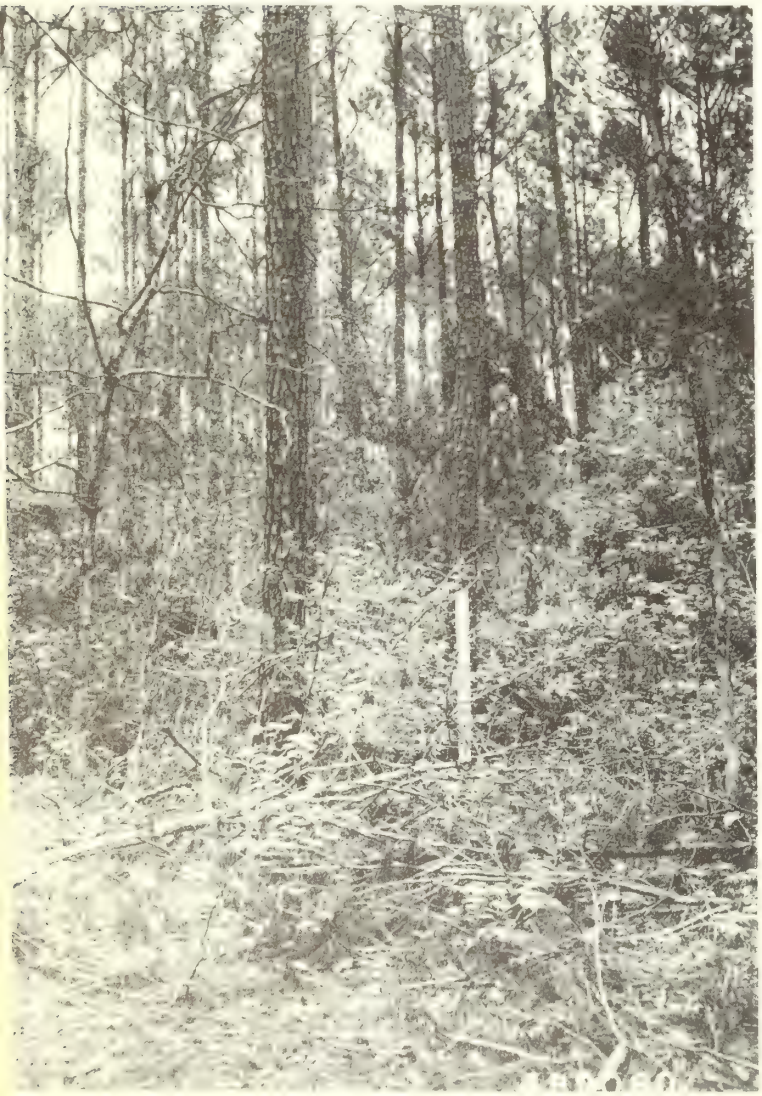
Barnette and Hester (1930), studying the effect of burning on soil in Florida, compared the soil beneath a virgin longleaf stand with soil on an area that had been burned almost annually for 42 years. They state that the organic matter and nitrogen content were greater on the unburned site. It should be noted that the areas studied were about 80 miles apart and that all timber had been cut from the burned area about 3 years before the measurements were made.

In contrast, Greene (1935), while working in the longleaf pine region of Mississippi, found that burned soils contained 1½ times as much nitrogen as soils protected from fire, and that burning increased the organic matter content 1.6 times in the surface 6 inches of soil. These increases are attributed to the decay of plant roots; the annual use of fire approximately doubled the growth of grasses and legumes.

Studying the soil fauna of burned areas, Heyward and Tissot (1936) noted that although the same microfaunal groups were found in both burned and unburned soils, the top 2 inches of the unburned mineral soil contained eleven times more animals than the corresponding depth on the burned areas. They state, "The diversified active soil fauna of the unburned areas is believed responsible for the penetrable and well aerated soil typical of such areas. This is in striking contrast to the more compact, less porous soil of frequently burned areas in which animal activities are much less abundant."

Investigating the soil temperatures during fires, Heyward (1938) states, "An important point brought out by the present study is the fact that, at a soil depth of only ⅛- to ¼-inch, the heat generated by hot forest fires in the longleaf pine region is insufficient to destroy organic matter. Since the maximum temperature recorded was approximately 275°F., it is clear that organic matter was neither charred (and thereby made resistant to decomposition) nor destroyed by heat generated by these fires."

Burns (1952), in studying the effect of fire on level sandy soils in New Jersey, concludes that: "1. Moderate burning treatments benefit the mineral soil chemically and probably have favorable effects on the forest floor. 2. Annual burning for long periods has unfavorable effects on the forest floor but benefits the mineral soil chemically. 3. Controlled burning is of little or no importance from the standpoint of the physical properties of the mineral soil."



Very comprehensive literature reviews and lists of references are found in the works of Shantz (1947) and Burns (1952).

Results of studies concerned with the effect of fire on soil have often been contradictory. Some of the contradiction undoubtedly comes from variation in study design, sampling techniques, and analytical procedures. However, some of the differences are from variation in sites which have been studied. It should not be expected that all conclusions drawn from studies of mountainous soils can be applied to coastal plain areas, or that results from a site with a thick mor humus type are applicable to an area with a mull humus type.

A universal answer to fire effects has not been, and probably will not be, found because of the variations in the soils, climate, and vegetation of the forested regions of the country.

METHODS

Area

The experimental areas for this study were in previously unmanaged but well-stocked, even-aged, loblolly pine stands that contained uniformly distributed, heavy understories (fig. 1). In each case the loblolly pine overstories also had some scattered shortleaf pine (*Pinus echinata* Mill.), an occasional longleaf pine, and miscellaneous hardwoods. The Santee plots, installed in a 40-year-old stand, had 3 light intermediate cuts, one at the beginning of the study followed by 2 cuts at 5-year intervals. The 30-year-old stand on the Westvaco forest was cut twice, at the beginning of the experiment and 10 years later.

Figure 1.—Stand conditions at the Santee Experimental Forest location in 1947 before any prescribed burning. Small understory stems are mainly sweetgum and southern bayberry.

All were commercial operations, in which the stands were thinned mainly from below, with very little disturbance of the overwood or understory. The understories consisted of many hardwood tree species. Approximate stocking by species groups was 60 percent gum (*Liquidambar styraciflua* L.) and (*Nyssa sylvatica* Marsh.), 30 percent mixed oaks (*Quercus* spp.), and 10 percent other species. Many shrubs were also present, including pepperbush (*Clethra tomentosa* Lam.), and gallberry (*Ilex glabra* L., A. Gray). Much of the understory at each location was about 15 years old, and dated from the last wildfire.

Both experimental forests lie within the flatwoods portion of the coastal plain at elevations of about 40 feet above sea level. The burning experiment was installed on Coxville very fine sandy loam, a poorly drained soil with very slow surface runoff and medium to very slow permeability. The soil occurs on level to slightly undulating terrain and is found over much of the lower coastal plain of South Carolina, both in the higher and lower flatwoods areas. Characteristically, the soil has a surface layer of 2 or 3 inches of dark grey, very friable, fine sandy loam which blends into a light grey, very friable, fine sandy loam with some yellowish mottlings appearing at a depth of about one foot. From 12 to 20 inches there is a mottled light grey, yellow to reddish-yellow, slightly plastic, fine sandy clay loam which overlays a clay containing mottlings of red, yellow, and grey.

The whole profile is very acid, low in nutrients, and the organic matter content decreases sharply below the surface 3 or 4 inches.

Surface runoff is fairly slow because of nearly level topography; during wet seasons water stands in depressions for several days following rains.

The soils on the two areas differ in depth to the clay layer; on the Santee the clay layer is about 12 inches below the surface, and on the Westvaco it is about 4 inches below the surface. This probably accounts for the difference in site index between the two areas: 95 on the Santee and 90 on the Westvaco land.

Plots and Data Collection

The study is based on prescribed burning tests carried out on ¼-acre plots located in the two previously described loblolly pine stands. Three replications of all treatments are at the Santee Forest location and two at Westvaco. Thus there were five plots for each of the following five treatments: annual winter fire, annual summer fire, periodic winter fire, periodic summer fire, and control (no fire). Soils were studied on all 25 plots.

On the annual fire plots there were ten consecutive fires from the time the study began until the soil data were collected. The periodic plots received two fires during this period. All of the winter and summer periodic plots were burned in 1947; however, the winter plots were reburned in 1951 and the summer plots in 1954.

On each plot, 15 random samples were collected in the surface 4 inches of soil. An undisturbed core (2 inches deep, 3 inches in diameter) was taken from the 0-to 2-inch and 2- to 4-inch depths. Immediately next to each core, a small bag of loose soil was collected for organic matter and nutrient analyses. Analytical work was directed by the Union Soils Laboratory of the Southeastern Forest Experiment Station.

Core samples were analyzed in the laboratory according to procedures given by Hoover *et al.* (1954). Determinations included bulk density, percentage by volume of detention and retention pores, and percolation rates.

Loose soil samples were passed through a 0.5 mm. sieve and organic matter was determined by the loss-on-ignition (450° C. for 4 hours) and a modification of the Walkley-Black wet combustion method (Jackson, 1958). Loss-on-ignition measures elementary carbon (*e.g.*, charcoal) while the wet combustion method excludes 90 to 95 percent of it. Other chemical analyses on composites of the loose samples included nitrogen, phosphorus, potassium, calcium, magnesium, and soil reaction.

In addition, four to eight samples from each of the surface organic layers were collected from the Santee plots only. On the control plots the humus type was a duff mull. These samples were 1 square foot in size and included all organic material down to mineral soil. They were oven-dried and then burned in a muffle furnace to eliminate the weight of mineral matter inadvertently picked up during the sampling. Therefore, the reported forest floor weights are expressed in pounds per acre on a volatile matter basis, rather than on an ovendry basis.

RESULTS

Physical Properties

The physical properties of pore space, percolation, and bulk density are important from the standpoint of erosion and the growth of vegetation. Growth is dependent on aeration and water movement in the soil (porosity and percolation rates are estimates of these) and in general is better on soils with low bulk density, high detention storage space, and high percolation rates.

Bulk density, a measure of the solid particles per unit volume, gives estimates of porosity and relative compactness of the soil. In general the bulk density of mineral soils ranges from less than 1.0 for porous soils to around 1.5 for compact ones.

The total porosity, or volume of air in the soil, can be separated into two parts. The large pores are those which detain water for only a day or so and their volume is called detention pore space. The small pores are those which retain water for considerable periods of time against the force of gravity and their volume is called retention pore space. The sum of the detention and retention pores is equal to the total porosity.

The percolation rate, a measure of the movement of water through soil, is expressed as inches per hour. Since the sample collected is but a segment of the profile of the soil, and is subjected to unnatural wetting conditions in the laboratory, these rates are only relative.

As is true of most soils, the bulk density in the surface 2 inches on the study plots is considerably lower than that of the 2 to 4 inch depth, showing that the surface soil is looser and more porous than that beneath (table 1). Detention or large pore space is also greater in the surface 2 inches. There is a close relationship between the percent by volume of detention pore space and percolation rate ($r=.80$).

Statistical analysis of the data showed no significant differences between treatments for any of the physical soil properties measured for either depth. Although some of the tabular values differ considerably, the within-plot variation prevented the differences from being significant. It appears that the various burning treatments, in comparison with the control, have neither benefited nor adversely affected the physical soil properties measured.

Table 1.—Some physical properties in the upper four inches of the soil related to fire treatments

Treatment	Bulk density	Retention pore space	Detention pore space	Percolation rate
	Grams per cubic centimeter	*Percent by volume*	*Percent by volume*	*Inches per hour*
0- TO 2-INCH DEPTH				
Annual winter	0.98	36.60	20.57	8.52
Annual summer	1.01	38.53	17.13	5.13
Periodic winter	1.10	35.89	17.91	4.83
Periodic summer	1.02	35.99	21.50	8.96
None (Check)	1.04	36.08	19.58	8.10
2- TO 4-INCH DEPTH				
Annual winter	1.24	34.42	14.59	2.57
Annual summer	1.29	35.12	11.88	1.80
Periodic winter	1.35	32.09	12.70	1.84
Periodic summer	1.34	32.26	13.99	2.80
None (Check)	1.29	33.96	13.22	1.70

Organic Matter

Organic matter values for the surface 2 inches of the soil under the various treatments showed significant differences at the 1 percent level between the annual summer and the periodic winter fires, and between the annual winter and periodic winter fires (table 2). Differences, significant at the 5 percent level, were noted for both the annual summer and annual winter when compared with the control, and between the periodic summer and the periodic winter fires.

Thus, organic matter in the mineral soil increased with all treatments except the periodic winter fire. When results were first obtained as loss-on-ignition values, it was suspected that much of the organic matter measured was charcoal. A subsequent analysis of the same samples by the wet combustion method showed the ranking of the various treatments in the same order, although the organic matter was several percent less on all plots.

The organic matter incorporated in the surface 2 inches of mineral soil (measured by the wet combustion method), and that resting on the soil surface, is given on a weight per acre basis in table 3. Percentage by weight in the mineral soil was converted to pounds by using bulk density, or weight of the soil. Since bulk density did not differ significantly between the treatments, the average for all plots was used. Therefore, the ranking of treatments with respect to soil organic matter is the same whether results are expressed on a percentage or weight basis.

Table 2.—Organic matter content in surface two inches of the forest soil in relation to prescribed burning treatment

Treatment	Organic matter based on ovendry weight	
	Wet combustion	Loss on ignition
	Percent	*Percent*
Annual winter fire	10.76	15.38
Annual summer fire	10.80	16.00
Periodic winter fire	7.04	8.14
Periodic summer fire	9.49	10.16
No fire (Check)	7.79	9.71

Table 3.—Weight of organic matter in pounds per acre for the surface two inches of mineral soil and the litter layer by various prescribed burning treatments

Treatment	Time since last burned	Organic matter		
		In mineral soil	On surface	Total
	Years	*Pounds*		
Annual winter fire	0.75	50,210	4,990	55,200
Annual summer fire	.25	50,390	3,860	54,250
Periodic winter fire	4.75	32,850	16,670	49,520
Periodic summer fire	2.25	44,280	9,520	53,800
No fire (Control)	25+	36,350	16,580	52,930

Apparently the maximum forest floor weight under the stand conditions studied is about 17,000 pounds per acre, as found on the control plots (fig. 2). The presence of an equivalent amount of surface organic matter on the periodic winter burn plots, however, is considered not so much the result of the accumulation since the last fire (4.75 years) as it is the small amount of fuel consumed by each fire. This is borne out by a supplemental measurement made on one plot after a periodic winter fire that showed only 4,000 pounds of organic matter per acre consumed by the single fire. In contrast, the periodic summer burns appear to be somewhat more intense, a fact reflected by the tabular values that show less than 10,000 pounds of surface material per acre even after 4 years. Some unburned organic matter remains on the surface even after 10 annual fires (winter or summer), as evidenced by the 4,000 to 5,000 pounds per acre measured shortly after the last burn but before the autumn fall of needles, twigs, bark, etc. (fig. 3).

Figure 2.—Surface organic matter on unburned plot. In foreground the organic matter has been removed to show depth to mineral soil.

Figure 3.—Bird's eye view of forest floor on annual summer burn plot. Frame is 2 feet square and encloses area showing residual surface organic matter left after last burn. Area outside frame shows about one year's accumulation following last burn.

All plots have about the same total amount of organic matter present, but the vertical location of the material differs. Assuming the forest floor is not washed away, it is lost from the site by oxidation. The rate of oxidation depends on the treatment applied to the forest, whether it be burning, clear cutting, or some other silvicultural practice.

In an undisturbed forest floor the material slowly disintegrates and decomposes. Some of it moves into the mineral soil; some of it goes into the atmosphere as carbon dioxide and water. The material moving into the mineral soil becomes soil organic matter and a slow rate of decomposition continues until the material disappears. When a forest floor is burned there is a rapid decomposition and much of the material moves quickly into the atmosphere. The fine residue moves down into the mineral soil. This charred matter is also slow to decompose and with continued fires it tends to build up in the surface layers of the mineral soil.

Chemical Properties

A composite was taken from the 15 samples of loose soil on each plot and analyzed for nitrogen, phosphorus, potassium, calcium, magnesium, and acidity. Total nitrogen was determined by the Kjeldahl method; available phosphorus was extracted with Bray No. 2 extractant using 5 grams of soil and 50 ml. of solution, shaking for 5 minutes, and analyzing colorimetrically; potassium, calcium, and magnesium were measured as exchangeable cations on a flame photometer after being extracted in 1 N ammonium acetate; and pH was measured on a soil paste with a glass electrode. These standard procedures are described by Jackson (1958).

The results of this work, shown in table 4, are related quite closely with the organic matter content of the different treatments. In general, the greatest amount of nutrients was found on the annual summer and annual winter burns, and the minimum quantity on the periodic winter fire.

Table 4.—Amount of nutrients and pH in surface four inches of soil as affected by prescribed burning treatment

Treatment	Nutrients					
	N	P[1]	K	Ca	Mg	pH
	- - - Parts per million - - -					
0- TO 2-INCH DEPTH						
Annual winter fire	1664	24	56	282	86	4.4
Annual summer fire	2038	26	54	435	96	4.8
Periodic winter fire	1129	14	29	168	48	4.2
Periodic summer fire	1478	19	36	252	52	4.3
No fire (Control)	1238	13	36	174	52	4.2
2- TO 4-INCH DEPTH						
Annual winter fire	862	13	30	86	42	4.6
Annual summer fire	834	8	24	94	39	4.7
Periodic winter fire	577	9	19	68	20	4.5
Periodic summer fire	712	9	21	96	24	4.6
No fire (Control)	702	7	24	85	34	4.5

[1] The Truog method as used on agricultural soils yielded but 3 to 7 ppm of phosphorus (no significance between treatments).

This same trend holds for both the 0- to 2-inch and 2- to 4-inch layers. Significant differences develop between treatments for the magnesium content in the 0- to 2-inch soil layer; amounts on the annual summer fire plots are greater than those on either of the periodic treatments or the control (1 percent level). For available phosphorus content in the 0- to 2-inch depth both annual treatments contained significantly more than in the control and periodic winter treatments, and the annual summer fire was greater than the periodic summer fire (5 percent level). None of the other treatment differences given in the table are significant at the 5 or 1 percent levels.

DISCUSSION

Since the physical properties of the soil studied are measures of compactness and water movement in the mineral soil, any changes should indicate whether the soil has been improved or depleted as a result of prescribed burning. It should be realized, however, that the sites studied have all had many burns in the past (charcoal was evident in A_1 horizon of control plots) and that the period of experimentation covers but an infinitesimal part of the life of the soil.

The type and frequency of fires used had no detrimental effect on bulk density, porosity, or percolation rate of the soil. All of these factors are somewhat dependent on the organic matter in the soil because the organic material tends to "fluff-up" the mineral soil. The data in tables 1 and 2 indicate the relationship between the bulk density and organic matter content of the surface two inches of mineral soil. The two types of annual fire plots have the lowest bulk density and also the highest organic matter content, whereas the control and periodic winter burning plots have the highest bulk density and the lowest organic matter content.

An increase in organic matter following fire, when measured as loss-on-ignition, has been noted by Heyward and Barnette (1934) in their studies of soil beneath longleaf pine. Shantz (1947) claims that this and other studies are deceptive because "loss-on-ignition, never reliable as a method in determining the organic matter in soils, is especially misleading when applied to the southern soils." It is true that loss-on-ignition values are only estimates of organic matter, and if charcoal is present in the soil the estimates are less reliable. Nevertheless, there was good correlation between the ignition and wet-combustion methods used in this study. Ignition values were always higher than the wet-combustion values, the difference varying from 5.20 percent for the annual summer fires to 0.67 percent for the periodic summer fire (table 2).

The organic matter beneath the burned sites is very black and gives the appearance of fine bits of charcoal. Analysis by the wet-combustion method, however, which measures only 5 to 10 percent of the charcoal, still shows an increase in organic matter over the unburned areas. Much of the burned forest floor is not converted to ash, and the material which appears to be charcoal is actually charred material which tends to decompose slowly.

Heyward (1938) found that the maximum temperature in the surface ¼ inch of mineral soil was 275° F. Although temperatures were not measured in the present study there is no reason to assume they would be higher. Except for the initial burn that all plots except the control received, the amount of forest floor, or fuel, was probably no greater than Heyward encountered. Small test burns have shown that undecomposed organic matter buried ¼ inch below the soil surface is not charred even under a heavy forest floor. Therefore, the high organic matter content of the burned soil is not from material charred in place, but is material charred on the surface and translocated into the mineral soil, primarily by water.

Some workers have reported the increase in organic matter in the mineral soil following burning was caused by stimulation of grasses. On the annual burns in this study, however, the annual vegetation was sparse (fig. 4).

The chemical analyses show that although the fertility level is low on all plots, the burning treatments have made additions of nutrients to the surface mineral soil in the past ten years. This is to be expected with the mineral elements where the topography is level and there is little or no erosion. Elements ordinarily bound up in the surface layers of organic material are released by fire.

It has often been stated that burning of the forest floor releases all of the nitrogen in the material. This may be true where fire converts the organic material into a white ash, but the charred material left on the soil surface after a fire does contain nitrogen. Tryon (1948) reports hardwood charcoal contains 0.21 percent total nitrogen and conifer charcoal 0.01 percent. Samples

Figure 4.—View of annual summer fire plot almost one year after 10th burn. Note absence of any understory vegetation.

of burned forest floor collected on the Santee Experimental Forest show appreciable nitrogen present. Litter from an unburned patch composed of recently fallen fuels contained 0.46 percent total nitrogen, and burned litter contained from 0.42 percent to 0.76 percent total nitrogen. All of these values are on an ovendry weight basis and an increase in the percentage of nitrogen in the burned material is a reflection of the concentration of nitrogen in the charred residue.

More than likely, the results of this study cannot be applied to sloping terrain or to sites on which the soil at the surface is not sandy. On the sites studied there is practically no horizontal movement of surface water. On sloping land, water moving over the surface would tend to carry ash and charred material from the site and at the same time material in suspension would settle out and plug the surface soil pores. Sealing of the surface by material carried in moving water would be more rapid on non-sandy soils. And of course, in the Piedmont, mountains, and sandhills, where soils, vegetation, and topography differ greatly from the coastal plain, prescribed burning might be detrimental to the site.

SUMMARY

A study was made from 1946 to 1956 of the effect of prescribed burning on soils beneath loblolly pine stands growing in the level, lower coastal plain of the Southeastern United States. Data were collected on two experimental areas located about 30 miles apart in South Carolina. The sites are comparable in that they have similar topography and surface soil texture. Annual and periodic fires over a ten-year period had no significant influence on the physical properties of the soil. Mineral elements, nitrogen, and organic matter tended to increase in the surface 4 inches of the burned plots.

Conclusions drawn from this experiment can probably be applied to the flat, low-lying, sandy surface soils of the region.

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